DOCUMENT RESUME

ED 445 950 SO 031 087

AUTHOR	Archer, Emma R. M.; Turner, Billie L., II
TITLE	Introduction to the Human Dimensions of Global Change. Hands-On! Developing Active Learning Modules on the Human Dimensions of Global Change.
INSTITUTION	Association of American Geographers, Washington, DC.
SPONS AGENCY	National Science Foundation, Arlington, VA.
ISBN	ISBN-0-89291-239-1
PUB DATE	1997-00-00
NOTE	139p.; Some type may not reproduce well.
CONTRACT	DUE-9354651
AVAILABLE FROM	Association of American Geographers, 1710 Sixteenth Street NW, Washington, DC 20009-3198; Tel: 202-234-1450; Fax: 202-234-2744; Web site: (http://www.aag.org/).
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	MF01/PC06 Plus Postage.
DESCRIPTORS	Active Learning; Demography; Ecology; *Environment; *Geography; *Geography Instruction; Global Approach; Higher Education; Human Geography; *Human Relations; Thinking Skills
IDENTIFIERS	Environmental Attitudes; *Global Change

ABSTRACT

This learning module aims to engage students in problem solving, critical thinking, scientific inquiry, and cooperative learning. The module is appropriate for use in any introductory or intermediate undergraduate course that focuses on human-environment relationships. The module provides students with a broad overview of the human dimensions of global environmental change and its implications for the future. According to the module, the complexity of global change is reduced to four basic and interactive parts: (1) human actions that initiate changes in the structure and operation of the biosphere; (2) the consequences of these actions on terrestrial ecology; (3) the combined efforts of the two on global climate; and (4) human responses to global change, with a focus on climate change. The module activities draw out the linkages and the human components of the topic and also raise broader questions about the concept of global change as a whole. The module contains 6 tables, 9 figures, a guide, a summary, an overview, a glossary, references for all units, supporting materials, and appendixes with additional resources and suggested readings. It is divided into thematically coherent units each of which consists of background information, teaching suggestions, and student worksheets, with answers expected for each activity. (Author/BT)

POOR PRINT QUALITY
Pgs 115 TO 124

Reproductions supplied by EDRS are the best that can be made
from the original document.

ED 445 950

HANDS-ON!

Introduction to the Human Dimensions of Global Change

SO031087

PERMISSION TO REPRODUCE AND
DISSEMINATE THIS MATERIAL HAS
BEEN GRANTED BY
S. J.
Natoli
TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)
1

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)
☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

An Active Learning Module
on the
Human Dimensions of Global Change

BEST COPY AVAILABLE

HANDS-ON!

DEVELOPING ACTIVE
LEARNING MODULES ON THE
HUMAN DIMENSIONS OF GLOBAL CHANGE

Introduction to the Human Dimensions of Global Change

Module developed for the AAG/CCG2 Project
"Developing Active Learning Module on the Human Dimensions of Global Change"

by

Emma R.M. Archer and Billie L. Turner II

Graduate School of Geography
Clark University
950 Main St.
Worcester, MA 01610

Significant revisions contributed by CCG2 Summer 1996 workshop participants Sarah Bednarz (Texas A&M University), Jennifer DeHart (Appalachian State University), Kirstin Dow (Rutgers University), Lisa Graumlich (University of Arizona), Jeremy Holman (Clark University), Ian Okabe (University College of the Fraser Valley), Frances Slater (University of London), Sarah Washburn (University of North Carolina), and Kay Weller (University of Northern Iowa).

Developing Active Learning Modules on the Human Dimensions of Global Change
"Introduction to the Human Dimensions of Global Change"

ISBN 0-89291-239-1

© 1997 by the Association of American Geographers
1710 Sixteenth Street NW
Washington, DC 20009-3198
Phone: (202) 234-1450
Fax: (202) 234-2744
Internet: gaia@aag.org

All materials included in this module may be copied and distributed to students currently enrolled in any course in which this module is being used.

Project director, Susan Hanson, Clark University, acknowledges the support of the National Science Foundation (NSF) to the Association of American Geographers (AAG) (Grant No. DUE-9354651) for the development of these teaching materials. Administrative support is provided through the AAG's Second Commission on College Geography (CCG2) and the AAG's Educational Affairs Director, Osa Brand, and her staff. General project support is provided by Clark University, Worcester, Massachusetts which also hosted a workshop to develop the modules further. The hard work of the conference participants evident in these materials is greatly appreciated. Kay Hartnett, Clark University, gave most generous and proficient graphic design advice. Module authors, co-authors, and other contributors are solely responsible for the opinions, findings, and conclusions stated in this module which do not necessarily reflect the views of the NSF or AAG.

This module is printed on recycled paper. Please recycle what you don't use.

Editor's Note

A major goal of this project, "Developing Active Learning Modules on the Human Dimensions of Global Change," is to disseminate instructional materials that actively engage students in problem solving, challenge them to think critically, invite students to participate in the process of scientific inquiry, and involve them in cooperative learning. The materials are appropriate for use in any introductory and intermediate undergraduate course that focuses on human-environment relationships.

We have designed this module so that instructors can adapt it to a wide range of student abilities and institutional settings. Because the module includes more student activities and more suggested readings than most instructors will have time to cover in their courses, instructors will need to select those readings and activities best suited to the local teaching conditions.

Many people in addition to the principle author have contributed to the development of this module. In addition to the project staff at Clark University, the participants in the 1996 summer workshop helped to make these materials accessible to students and faculty in a variety of settings. Their important contributions are recognized on the title page. This module is the result of a truly collaborative process, one that we hope will enable the widespread use of these materials in diverse undergraduate classrooms. We have already incorporated the feedback we have received from the instructors and students who have used this module, and we intend to continue revising and updating the materials.

I invite you to become part of this collaborative venture by sending your comments, reactions, and suggested revisions to us at Clark. To communicate with other instructors using hands-on modules, we invite you to join the Hands-on listserve we have established. We look forward to hearing from you and hope that you will enjoy using this module.

Susan Hanson
Project Director

School of Geography
Clark University
950 Main St.
Worcester, MA 01610-1477
ccg2@vax.clarku.edu

Table of Contents

Page

Editor's Note i

List of Tables v
List of Figures v

A Guide to This Module vi

Summary 1

Module Overview 3

1 **The Driving Forces of Global Change--Background Information** 4
  Humans as Driving Forces of Global Change 4
  Typology of Human Driving Forces 5
  Putting the Driving Forces Together 6
  The IPAT Identity 8
  Proximate vs. Non-Proximate Sources of Change 8
  Conclusion 9

Instructor's Guide to Activities 10
Student Worksheets 17
Answers to Activities 21

2 **Environmental Change in Terrestrial Ecosystems--Background Information** 23

Instructor's Guide to Activities 26
Student Worksheets 34
Answers to Activities 42

3 **Climate Change--Background Information** 45
  Global Warming and the Greenhouse Effect 45
  Climate Models 47
    Analogue Models 47
    General Circulation Models 48

Instructor's Guide to Activities 51
Student Worksheets 57
Answers to Activities 62

4

Human Impacts and Responses--Background Information 65
  Human Responses to Environmental Change 65
  International Responses to Climate Change 67
  Conclusion 69

Instructor's Guide to Activities 70
Student Worksheets 75
Answers to Activities 79

Glossary 81

References to All Units 85

Supporting Materials 89

Appendices 103
A: Additional Resources 103
B: Suggested Readings 106

List of Tables

Page

Table 1: Typology of Human Driving Forces 5
Table 2: My Personal Water Usage 18
Table 3: Typical Household Water Use in the United States 19
Table 4: Per Capita Water Consumption in Selected Countries 19
Table 5: Patterns of Change 23
Table 6: Developed and Developing Regions of the World 68

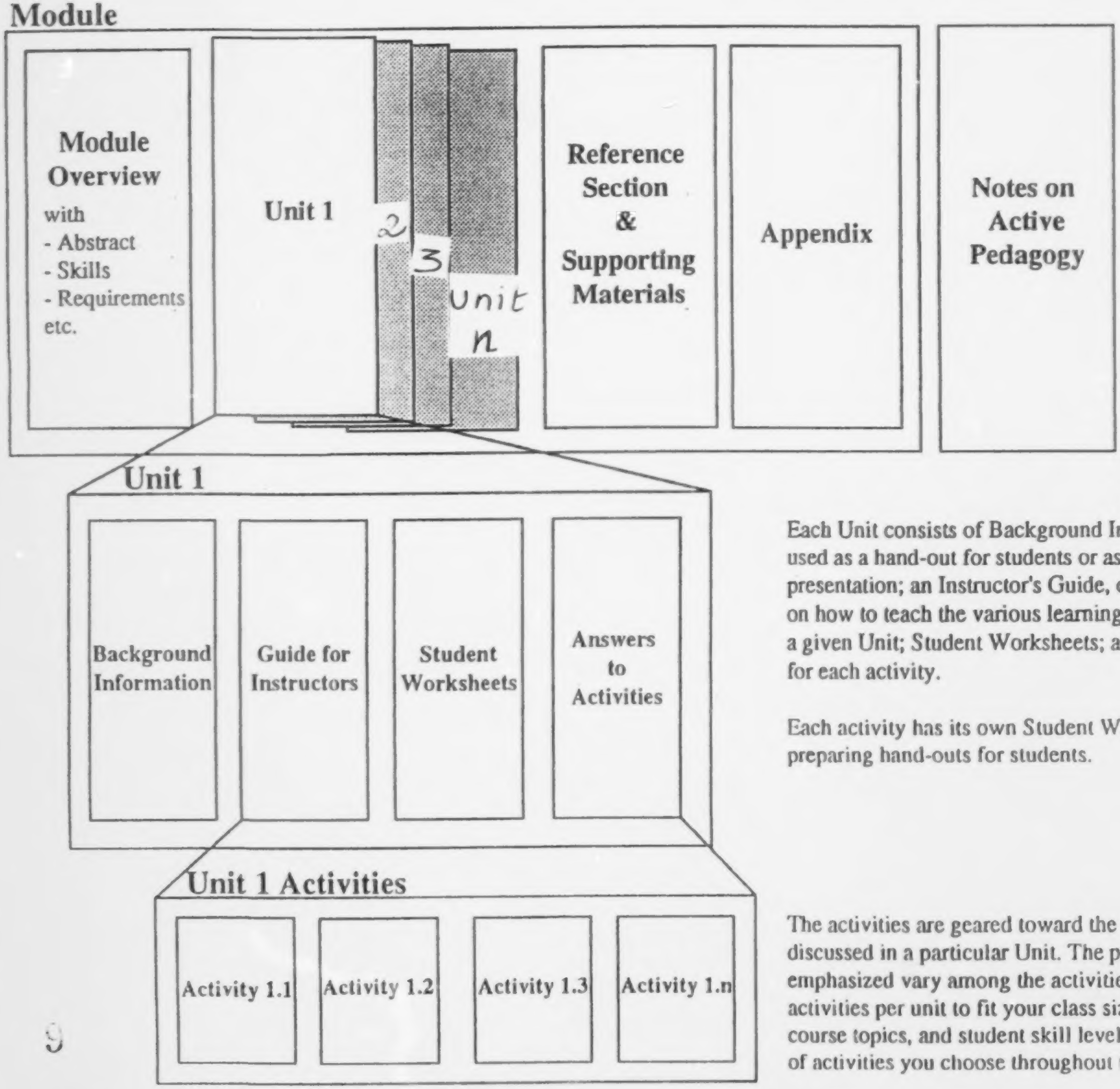
List of Figures

Page

Figure 1: Trends in the Transformation of Components of the Biosphere 5
Figure 2: World and Regional Population Estimates 6
Figure 3: GNP of World Regions 7
Figure 4: Links Between Terrestrial Change and Other Forms of Environmental Change 25
Figure 5: Relationships Between Variables 34
Figure 6: The Earth's Atmosphere and the Greenhouse Effect 46
Figure 7: The Earth's Climate System 48
Figure 8: GCM Temperature Response Scenarios 49
Figure 9: The Earth's Climate System 57

Guide to this Module

This guide is meant to help you navigate this module.


Module
Module Overview
with
- Abstract
- Skills
- Requirements
etc.
Unit 1
2
3
Unit n
Reference Section & Supporting Materials
Appendix
Notes on Active Pedagogy
Unit 1
Background Information
Guide for Instructors
Student Worksheets
Answers to Activities
Unit 1 Activities
Activity 1.1
Activity 1.2
Activity 1.3
Activity 1.n

The module is divided into Units, i.e., sections that are thematically coherent and that could, if necessary, stand alone. In addition, the module contains a Reference Section, Supporting Materials and an Appendix. The Supporting Materials can be used to facilitate the teaching of this module or simply to augment it with interesting ideas and information. Additional sections with further information may or may not be present, e.g., a list of accronyms, or a glossary. A separate section on Active Pedagogy comes with every module purchase.

Each Unit consists of Background Information that can be used as a hand-out for students or as the basis for an in-class presentation; an Instructor's Guide, consisting of suggestions on how to teach the various learning activities associated with a given Unit; Student Worksheets; and the Answers expected for each activity.

Each activity has its own Student Worksheet for ease of preparing hand-outs for students.

The activities are geared toward the theme(s) and concepts discussed in a particular Unit. The particular skills and themes emphasized vary among the activities. Choose one or more activities per unit to fit your class size, time, resources, overall course topics, and student skill levels. Be sure to vary the types of activities you choose throughout the module.

BEST COPY AVAILABLE

Summary: Introduction to the Human Dimensions of Global Change

Abstract

This module provides students with a broad overview of the human dimensions of global environmental change and its implications for the future. The complexity of global change is reduced to four basic and interactive parts: human actions that initiate changes in the structure and operation of the biosphere; the consequences of these actions on terrestrial ecology; the combined effects of the two on global climate; and human responses to global change, with a focus on climate change. Global environmental change is thus linked by the human, natural, and policy sciences. The module activities draw out the linkages and the human components of the topic and also raise broader questions about the concept of global change as a whole

General Module Objectives

- To provide an introduction to the problem and study of global environmental change
- To demonstrate the complexity of global environmental change and its origins in society and nature
- To demonstrate the interconnections of the basic human and natural components of global environmental change
- To involve students in activities that demonstrate the complexity and interconnectivity of the subject and its basic components
- To illustrate the extent to which students may affect and be affected by aspects of global environmental change

Skills

Students will acquire the following skills:

- ✓ plotting bivariate data
- ✓ reading maps
- ✓ interpreting bivariate data
- ✓ critical reading and interpretation of data and policy responses
- ✓ interpreting satellite imagery
- ✓ analyzing and interpreting maps
- ✓ creative writing

Activities

The types of activities in this module designed for individuals, small groups, and/or the entire class include:

- ✓ role plays/simulations
- ✓ group discussions
- ✓ quantitative data analysis/interpretation
- ✓ map/image interpretation
- ✓ creative writing
- ✓ qualitative data interpretation (including film, interviews, photos, diaries)
- ✓ debates

Material Requirements

- ✓ Student Worksheets (provided)
- ✓ Suggested Readings (some provided)
- ✓ Satellite and GIS images (provided)
- ✓ Graph paper
- ✓ Repeat photography (optional)
- ✓ Access to the World Wide Web (optional)
- ✓ Films (optional)
- ✓ World atlas

Human Dimensions of Global Change Concepts

- ✓ Global environmental change
- ✓ Biosphere
- ✓ Human driving forces and responses
- ✓ Terrestrial change
- ✓ Climate change
- ✓ Connectivity and complexity
- ✓ Transformation of the Earth
- ✓ Vulnerability
- ✓ Uncertainty

Geography Concepts

- ✓ Human-environment relationships
- ✓ Spatial relationships
- ✓ Spatial scale
- ✓ Earth system processes
- ✓ Place
- ✓ Climate

Time requirements

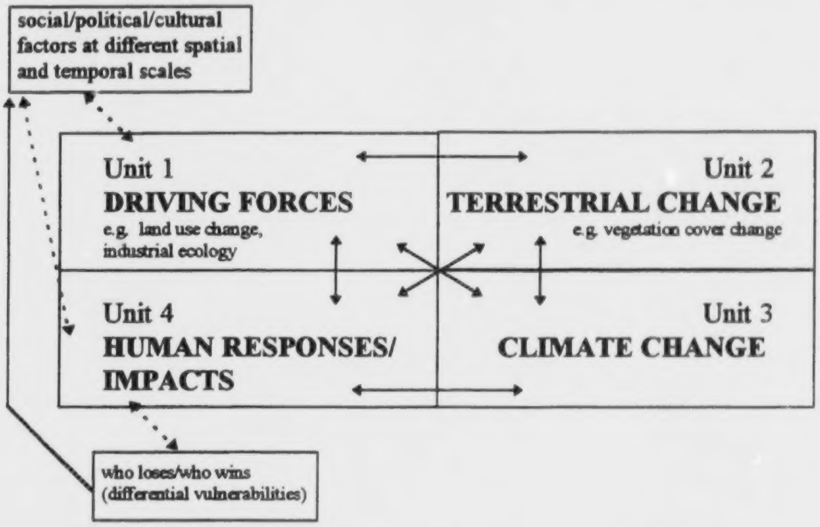
5-7 class days, plus additional time for students to complete homework assignments. There is reasonable flexibility in choosing activities and options in order to meet class size and/or time demands.

Difficulty

Introductory to intermediate. Most of the activities contain options that allow you to adapt the activity to the needs and skill level of your class. Because this is an introductory and overview module, some of the activities are written for students who have little to no experience with the subject of global environmental change. These specific activities have options that allow you to make them more challenging for students with more experience in the subject matter.

Module Overview

This module provides students with a broad overview of the human dimensions of global environmental change. The complexity of global change is reduced to four basic and interactive parts: human actions that initiate changes in the structure and operation of the biosphere; the consequences of these actions on terrestrial ecology; the combined effects of the two on potential climate change; and human responses to global change, with a focus on climate change. The following graphic illustrates these four components and serves as a framework for the module:


social/political/cultural factors at different spatial and temporal scales
Unit 1
DRIVING FORCES
e.g. land use change, industrial ecology
Unit 2
TERRESTRIAL CHANGE
e.g. vegetation cover change
Unit 4
HUMAN RESPONSES/ IMPACTS
Unit 3
CLIMATE CHANGE
who loses/who wins (differential vulnerabilities)

The phrase "human dimensions of global change" refers to the entire matrix shown above, not just to the left hand side, although the module emphasizes driving forces and human responses/impacts. The module has five broad objectives:

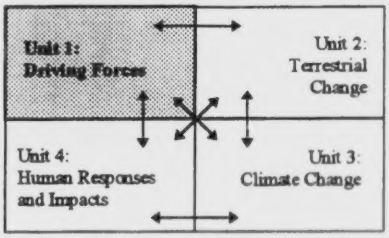
- To provide an overview of the problem and study of global environmental change;
- To demonstrate the complexity of this change and its origins in society and nature;
- To demonstrate the interconnections of its basic human and natural components;
- To involve students in activities that demonstrate the complexity and interconnectivity of the subject and its basic components; and
- To illustrate to students the extent to which they may affect and may be affected by aspects of global environmental change.

The module activities draw out the linkages and the human components of the topic; they also raise broader questions about the concept of global change as a whole (for example, how certain we can be of research findings provided to date). Students actively engage with the material through role-playing, group discussions, map interpretation, creative writing, debates, and quantitative/qualitative data analysis and interpretation.

1

The Driving Forces of Global Change

Background Information



How do the more than 5.7 billion humans that inhabit our earth affect the global environment? Do you personally contribute to global climate change or forest degradation? This unit attempts to answer these questions and provide an introduction to the role that humans play in environmental change.

Although we may speak of environmental change as if it were something new, the earth is constantly changing, driven by human and natural forces. The crash of ocean tides reshapes coast lines, winds push sand dunes across desert landscapes, rivers meander and scour new channels, and the construction of new shopping centers alters urban landscapes. These changes are most pronounced in the small envelope of the environment that sustains life called the **biosphere**.[1] The biosphere can be defined in at least two ways: (1) the zonal space extending from the immediate subsurface of the earth to the upper atmosphere; (2) the parts of the earth's atmosphere (air), hydrosphere (water), lithosphere (rock), pedosphere (soil), and cryosphere (ice) in which all livings things exist and interact. Changes to components of the biosphere occur at different times, at different spatial scales, and at different rates; such changes are usually interacting and interdependent. Thus, the earth can be visualized as a complex system of changing and interacting environmental domains.

Humans As Driving Forces of Global Change

This unit focuses on the changes to the earth system that are the product of *human activity*. Humans alter their environment in many ways; their activities bring about changes in land cover and landscapes, changes in the composition of atmospheric gases with resulting climatic effects, and changes in plant and animal species diversity.

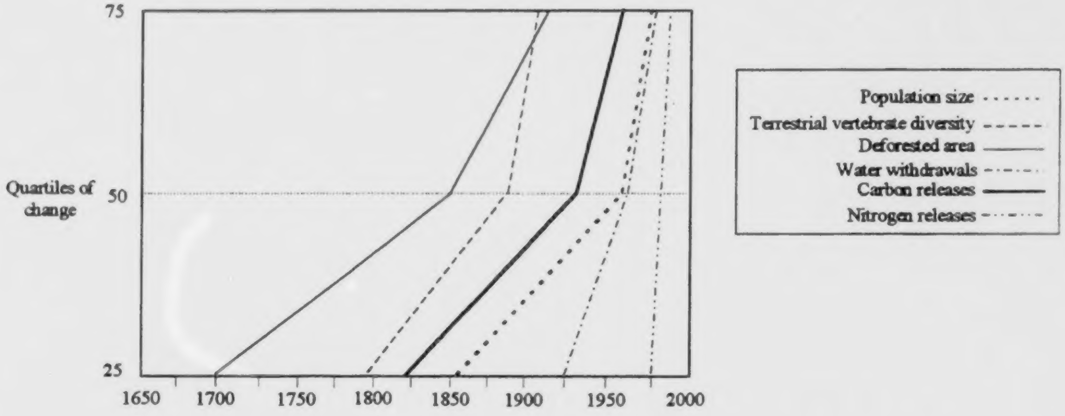
Figure 1 shows trends in human transformation of some components of the biosphere over time. The graph depicts the percentage change in human population, terrestrial vertebrate diversity, deforestation, water withdrawals, and some chemical releases since 1650. This graph, with time on the x-axis and percentage change on the y-axis, shows that through time, the amount of change to components of the biosphere has increased.

---

[1] Terms that appear in bold face can be found in the glossary.

BEST COPY AVAILABLE

Figure 1: Trends in the Transformation of the Components of the Biosphere



Source: Adapted from Turner et al. 1990. *The earth as transformed by human action.*
©1990 Reproduced with the permission of Cambridge University Press.

Typology of Human Driving Forces

What exactly are we talking about when we speak of human driving forces? What specific human activities have caused such rapid changes in the biosphere? The answer is subject to some debate, but for our purposes, the human driving forces of environmental change can be separated into three broad categories: population change, technological change, and socio-cultural and socio-economic organization (see Table 1).

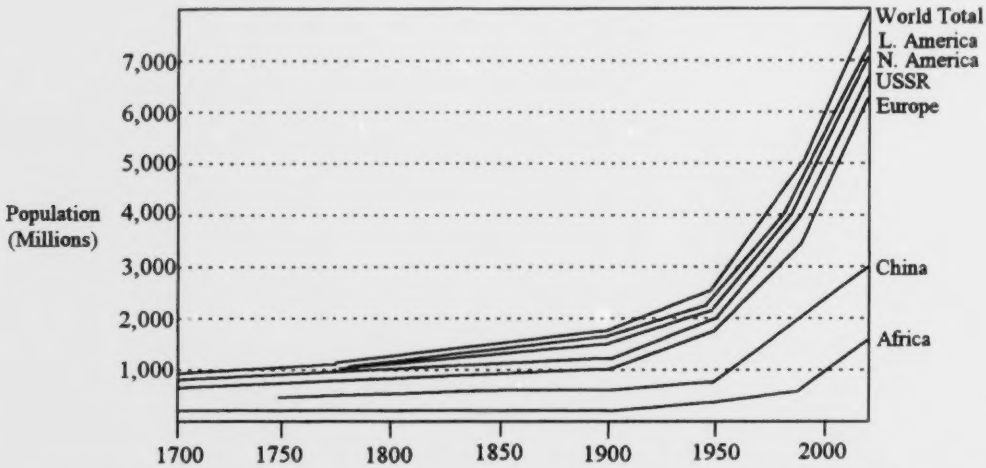
Table 1: Typology of Human Driving Forces

Population change	Population at the global scale (and at the regional scale in certain areas) is increasing at an increasing rate and is accumulating in settlements that stress the landscape (urbanization).
Technological change	Acts of technological innovation have become increasingly divorced from their environmental impacts. Thus, in addition to societal benefits, technology often contributes to environmental change or deterioration.
Socio-cultural and socio-economic organization	Economic institutions and markets, political economy, political ecology, and political institutions all affect the relationships between humans and their environment.

Population change at the global scale, and in certain areas at the regional scale, is increasing at an increasing rate. This means that not only is the population of the earth growing in absolute numbers but the *rate* at which it is growing is also increasing. Increases in population, as well as the concentration of a greater number of people in cities and in very dense agricultural settlements, stresses the landscape and puts increasing demands on the environment and its resources.

Figure 2 depicts changes in population growth for the world and various regions since 1700 and projects those changes beyond the year 2000. Africa, China, and the rest of Asia account today for a significant portion of global population. Notice also that it took almost 200 years for the world population to double from 1 to 2 billion people, but it took only 50 years for the global population to double again from 2 to 4 billion people. This is what is meant by the phrase "population is increasing at an increasing rate."

Figure 2: World and Regional Population Estimates



Source: Adapted from Turner et al. 1990. *The earth as transformed by human action.* ©1990 Reproduced with the permission of Cambridge University Press.

The environmental impacts of technological change are also important but are often overlooked or discounted when considering the human driving forces. For example, a technological innovation such as fertilizers or pesticides may provide benefits to society in the form of increased crop yields but it may also pollute the groundwater, increase the risk of human cancers, or increase the rates of mortality among beneficial insects and birds.

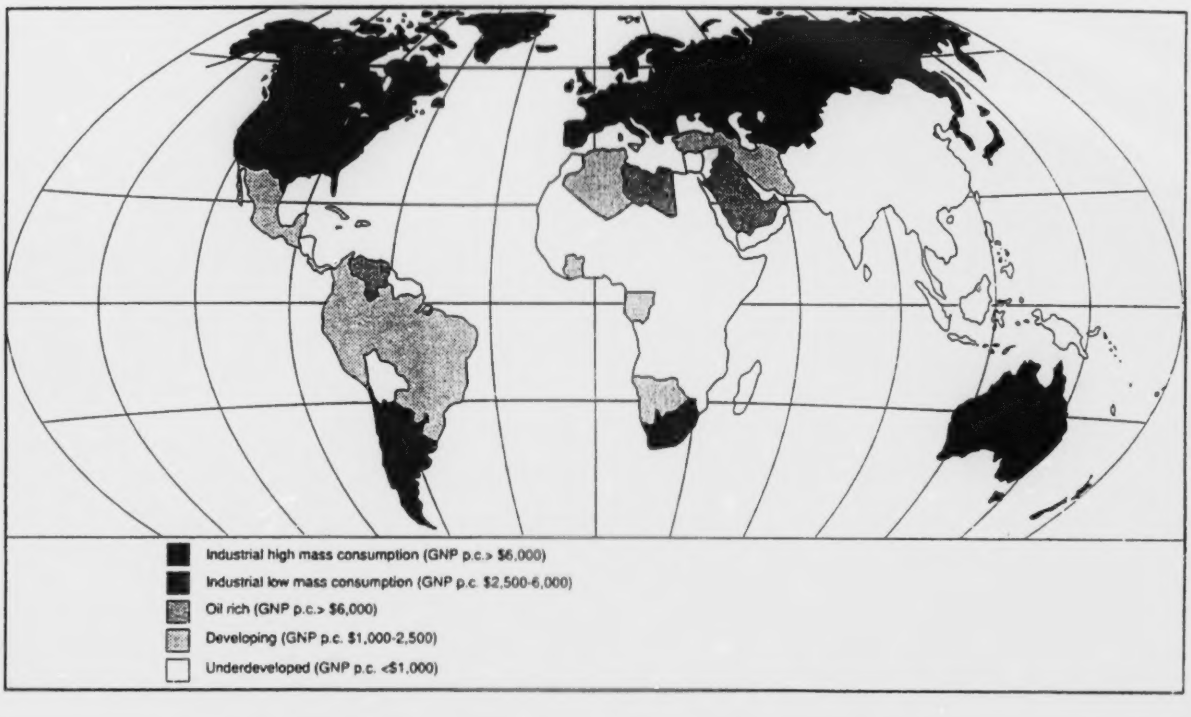
Finally, our ways of organizing as human beings are profoundly tied to environmental transformations. Although they are difficult to measure, economic systems, political systems, cultures, and traditions all affect the ways in which human beings relate to, utilize, and affect their environment.

Putting the Driving Forces Together

The configuration and operation of population change, technological change, and socio-economic/cultural organization structure the patterns of production, consumption, and impacts throughout the globe. Although China has a population of over 1 billion, other countries with fewer people consume more resources. North America, for example, accounts for a relatively small portion of the world's population, but because of its level of technology and its social and economic organization, it consumes a much greater share of resources and contributes a much larger portion of environmental changes. In other words, the ways in which population, technology, and society are arranged in different places produces a factor of *affluence*, or a measure of material goods, wealth, or quality of life, (among others) found in a society, country, or region.

Figure 3 is a map of Gross National Product (GNP) of various regions in the world. GNP is the value of the total output of goods and services produced in a country in a given time period and is used here as an indicator of affluence. It should be noted that GNP is not a perfect measure of a region's level of economic development. It does not account for unused resources or for the informal economy (economic activities not recorded by a government, such as domestic labor, street vending). Despite its limitations, Figure 3 is still a useful illustration of areas of mass consumption and development vs. areas of underdevelopment at a global level.

Figure 3: GNP of World Regions


■ Industrial high mass consumption (GNP p.c.> $6,000)
■ Industrial low mass consumption (GNP p.c. $2,500-6,000)
▨ Oil rich (GNP p.c.> $6,000)
▨ Developing (GNP p.c. $1,000-2,500)
☐ Underdeveloped (GNP p.c. <$1,000)

Source: Turner et al. 1990. *The earth as transformed by human action.*
©1990 Reproduced with the permission of Cambridge University Press.

The IPAT Identity

In 1972, Paul Ehrlich and John Holdren introduced a concept known as the IPAT (pronounced "eye-pat") equation as a way of describing the variables that interact to produce environmental change. The equation states that Impact = Population × Affluence × Technology or $I = P \times A \times T$. In other words, the magnitude (amount or size) of environmental change in an area (I) depends on the magnitude of demand created by the size of population (P) and its level of per capita consumption (A), both of which are influenced by the efficiency of production/consumption methods (T). All three of the factors influencing environmental impact and change are interrelated.

IPAT is often taken to mean that the telling factors in global environmental change are overpopulation, excessive affluence (or its opposite) and consumption, and inappropriate technology operating together. But most global environmental change is driven by *local* actions taken in our daily activities which are influenced by such factors as policies, rules, and regulations concerning the allocation of resources. For this reason, it may be more appropriate to expand the rather limited idea of the IPAT equation so that we understand human actions as outcomes of human agents within social structures. This viewpoint seems particularly relevant at the local and regional scale. Thus, while the earth as a closed system may function in terms of the IPAT equation, local or regional places may not. Environmental change at the local level may be driven by complex interactions among ideologies, beliefs, institutions, and markets, for example (Kasperson et al. 1995).

Proximate vs. Non-Proximate Sources of Change

So far we have looked at the human driving forces of global change. We can further refine our understanding of these driving forces by placing them into two groups -- proximate and non-proximate forces of global environmental change. **Proximate forces** are immediate human actions that directly alter the physical environment. We can group proximate forces into industrial metabolism (or ecology) and land-use/cover change. Industrial metabolism refers to processes involved with industrial production and consumption (e.g., large factories, energy production and consumption, transportation). Land-use/cover change includes human activities that alter either land and its vegetative cover or the human use of the land (e.g., deforestation, cropland intensification). Land-use/cover change will be addressed in more detail in Unit 2.

Of the two types of proximate forces, those dealing with industrial production and consumption produce about 70% of the radiative gases leading to climate change. Human activities that produce changes in the land account for the remaining 30% of the radiative gases; such activities can also affect **biodiversity**, **ecosystem** fragmentation, and basic sustainability. To the human sciences, the critical need is to better understand the societal forces that drive industrial metabolism and land-use/cover change. This requires that we look beyond proximate forces to the factors that actually drive proximate forces, known as **non-proximate forces**.

Non-proximate forces are forces of change that underlie, at various levels, the proximate forces. For example, deforestation can be explained as a result of the proximate force of slash and burn activities. But what causes farmers to slash and burn? To answer this, we need to consider the non-proximate or *distal* forces of deforestation, which may include factors such as migration into the area, political decisions encouraging migration, the political-economic context of the area, or global market forces. Each of these non-proximate sources of change underlie the proximate action of slash and burn activities.

How do we conceptualize these forces? At the global or "macro" scale, proximate forces change according to the demand for natural resources and the ways in which resources are produced and consumed. At the local scale, other factors may be more important in explaining driving forces. The important point is that driving forces have different characteristics at different geographical scales.

Conclusion

So far, we have seen that a variety of factors related to human activity interact to produce global environmental changes, and we've seen that these factors may vary from place to place and at different geographic scales. In the remainder of this module, we will look specifically at two types of global environmental change -- land-use/cover change and climate change -- and will consider the ways that human activity has led to these changes and how we can respond to them.

1

The Driving Forces of Global Change

Instructors Guide to Activities

Goal

Students make connections between their daily lives and global environmental change; automobile usage and freshwater consumption are used to illustrate these links. Students recognize that global environmental changes are affected by individual actions, the cumulative nature of the actions of many individuals, and by the policies that guide or influence their activities.

Learning Outcomes

After completing the exercises associated with this set of activities, students should be able to:

- recognize their role as driving forces of environmental change;
- access data from a public source;
- estimate variables for and perform "back of the envelope" calculations;
- delineate a drainage basin and identify human activities within it; and
- calculate daily water consumption and compare it to other countries.

Choice of Activities[2]

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select those that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

1.1 How Many Automobiles?	-- Basic "back of the envelope" calculations and unit conversions
1.2 Where *Does* My Water Come From?	-- Investigation of source of freshwater and presentation in written or poster format
1.3 The Water Bill	-- Calculation of personal daily water use
1.4 Crystal Clear Water	-- Drainage basin delineation and identification of human-induced changes within it

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

---

[2] For additional active learning materials and activities on human driving forces and environmental change, see the following modules in this series: *Population growth, energy use, and pollution: Understanding the driving forces of global change* (Kuby 1996) and *Living in the biosphere: Production, pattern, population, and diversity* (Brown 1996).

- Background Information to Unit 1 (all students should read)
- Turner, B.L. II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds. 1990. *The Earth as Transformed by Human Action*. New York: Cambridge University Press, Chapter 1 and selections from Chapters 2-5.
- Stern, P., O.R. Young, and D. Druckman, eds. 1992. *Global environmental change: Understanding the human dimensions*. Washington, DC: National Academy Press, introductory chapters.

Activity 1.1 How Many Automobiles?

Goals

This starter activity is provided as a way to capture students' attention, to engage them, and to stimulate their thinking about the driving forces of environmental change. There is some flexibility in how the instructor can structure the activity.

Skills

✓ data collection
✓ basic calculations using data collected
✓ unit conversions (i.e., feet to miles)

Material Requirements

- Motor vehicle registration data (provided for states in *Supporting Materials 1.1*)
- Calculators

Time Requirement

30 minutes (if students are provided with data)

Tasks

Begin by asking some of the following questions:

- How many people in this class own, or have use of, an automobile on a full-time basis?
- How many people do you think own cars in the US? How many in Mexico? India?
- Why should we care how many people own or use cars?
- Do you ever think about how what you do personally might affect global environmental change?
- Do you know what effect your automobile has on the global environment?

Ask students to take out a sheet of paper, a pencil, and a calculator and do various "back of the envelope" calculations based on the number of registered automobiles in their state, county, or city. Get students to estimate a value for each of the six variables provided below. Use the example questions in the box as a guide for using the activity. Note that the number of automobiles registered in each state has been provided and can be given to students by the instructor (*Supporting Materials 1.1*). You may wish to have the students research the data, in which case, this activity may be more appropriate as a homework assignment. The data can be found in *Statistical Abstracts of the US* (US Bureau of the Census) or by calling the appropriate local Department of Motor Vehicles.

Variables:

1) # of registered vehicles in your state (provided), county, or city
2) cost of a gallon of gasoline ($1.40 or going rate)
3) average gas mileage of a vehicle (25 miles)
4) approximate vehicle length (15 feet)
5) average miles driven per year per vehicle (12,000)
6) pounds of CO_2 produced per gallon of gasoline[3] (about 20 lbs)

Example:

1. ***There are approximately 3.3 million cars in Massachusetts. Estimate how long a line of cars would be in miles, if they were all stuck "bumper to bumper" on the highway at the same time.***

   3,300,000 cars × 15 feet/car × 1 mile/5280 feet = **9375 miles**

2. ***Using an atlas, see how far this line of cars would stretch across the country or the world.***

   Compare this number to the distance between the university and another large city. The circumference of the earth is about 25,000 miles.

3. ***If each car travels 12,000 miles per year, how much gasoline is used per year?***

   3,300,000 cars × 12,000 miles/car × 1 gallon/25 miles = **1,584,000,000 gallons**
   This amount is equivalent to about 100,000 tanker trucks of gasoline (each tanker truck holds about 15,000 gallons).

4. ***What is the total cost of the gasoline used?***

   1,584,000,000 gallons × $1.40/gallon = **$2,217,600,000**
   Compare this amount to how much your state spends on education or other programs. Also, be sure to discuss that this amount reflects the costs to consumers and may not include indirect costs like environmental impacts. You might also discuss how much of this amount goes to the government in the form of taxes and how much goes to the oil corporation.

5. ***How much carbon dioxide is produced from these vehicles?***
   1,584,000,000 gallons × 20lbs CO_2/gallon = **31,680,000,000 lbs CO_2**

---

[3] Variables 2 through 5 are reasonable estimates that may vary. Variable #6 has been taken from Jacques (1992). This value assumes a 99% oxidation rate.

Extensions for the Activity (optional)

- Students design a 1-2 page plan for reducing personal car usage. This can also be done in groups of 2 or 3. Through this process, students should identify some of the steps they can take immediately, as well as some of the barriers to reducing their reliance on automobiles (i.e., lack of public transportation, decentralization of market places, etc.).
- Divide students into groups and ask them to act as consultants for their city's Environmental Protection Department. They should prepare a feasible plan for reducing automobile usage in their city to be presented to the city council.

Activity 1.2 Where *Does* My Water Come From?

Goals

Students begin to create a "sense of place" in which they recognize their links to the community and their environment. This activity can be used alone but is intended to be followed by Activity 1.2 and Activity 1.3.

Skills

- ✓ primary data collection
- ✓ essay writing

Material Requirements

- *Student Worksheet 1.2* (provided)

Time Requirements

This exercise should be assigned as homework. Allow 10-15 minutes to introduce the project in class and an additional 5-7 days for students to complete their investigation and summary.

Tasks

In this activity, students (individually or in small groups) trace their water supply from its source to the tap *and* from the drain to its disposal. Students may use whatever sources they choose from which to gather information; they can contact the local municipal water company, conduct a windshield survey, or interview relevant community members or officials. You might suggest that each group select a delegate to contact any local agencies so as not to overwhelm the agency with student inquiries. Students can choose to present their results either in written form or in a poster that graphically depicts the water supply from source to tap.

As an alternative to the water example, you might ask students to focus on other types of resources. For example, students could investigate the sources of natural gas for heating and cooking, gasoline and oil for automotive use, lumber and wood products for home building, or coal, water, or oil electricity production. The point is for students to identify how local consumptive activities can have regional or global effects.

Activity 1.3 The Water Bill

Goals

Students make connections between individual behavior (resource consumption) and the global environment using the common resource of freshwater. Students become aware of the amount of water they consume each day and how this compares to other countries around the world. Using freshwater simply as an example, this activity illustrates the differential resource consumption patterns of the countries of the world as discussed in the Background Information to Unit 1. This activity can be used alone but is intended to build upon the learning in Activity 1.1.

Skills

✓ basic calculations
✓ identification of personal behavior and habits

Material Requirements

- *Student Worksheet 1.3* (provided)

Time Requirements

One class period (50 minutes)

Tasks

For one day, students keep track of the activities in which they use or consume water and calculate a total daily usage from data provided. Students then compare this with estimates of daily water usage from developing countries and begin to eliminate activities from their list until they have reduced their consumption to that of the developing country's. To extend this activity, you could (1) ask students to keep track of their water consumption for several days or even a week or (2) ask students to do additional research on water consumption and estimate how much water they use daily through *indirect* consumptive activities (i.e., water used to produce paper or to grow vegetables).

Optional activity

In addition to the task above, ask students to live for a day on the amount of water that an average person in Mozambique or Haiti would use in a day (2.7 gallons, 1.2 gallons respectively). Much like the well-known child care activities where students are asked to "care" for a 5 lb. bag of flour for a week, students could be asked to bring in 2 empty gallon jugs for filling. Then, on their honor, they must live from those gallons for a day. This means that they must bathe, cook, drink, and flush from those supplies only. Obviously, this does not include indirect consumption of water, such as water used to grow food, or used to produce other products students may use. The gallons per day figures that students will use have been calculated for domestic use only. These numbers do not include indirect uses such as agricultural or industrial withdrawals.

Activity 1.4 Crystal Clear Water

Goals

Students identify how the demand for a resource (water) has affected the land cover and landscape through time. In addition, students identify activities within the local drainage basin that could affect their water supply.

Skills

- ✓ drainage basin delineation
- ✓ map reading and interpretation

Material Requirements

- local area topographic maps
- local land-use maps
- tracing paper

Time Requirements

Option 1: 15 minutes in class to introduce; allow 7-10 days outside of class for students to complete the project and one additional class period for students to present their projects to the class.

Option 2: one class period (50 minutes) or alternatively, assign as homework

Option 3: 15 minutes in class to introduce; allow 5-7 days outside of class for students to complete their research and to write their essay.

Tasks

The options that follow should allow you to adapt this activity to fit your class situation and time constraints.

Option 1

Students obtain a topographic map of the area, locate their water supply on the map (i.e., river, aquifer, etc.), and trace/delineate the drainage basin boundaries. From fieldwork, windshield surveys, planning maps, or other sources, students locate existing land-use activities within the basin such as residential, industrial, commercial, agricultural, and recreational uses and draw them on their basin map. Students should research the consequences of having these activities within the basin and how they may affect the water supply. Finally, students should consider how the demand for freshwater in their community has had an impact on the land-use/cover of the area (i.e., flooded areas from dam construction, areas cleared for new facilities such as waste water treatment plants, or salinization from irrigation or aquifer draw-down).

Products from Option 1

- A traced map of the drainage basin boundaries, with the water supply and land-use activities clearly identified on the map.

- A 2-3 page essay that identifies land-use activities and their impacts on the water supply, as well as the impacts of water demand on land-cover in the area.
- A brief presentation of the project to the class (5-10 minutes)

◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆

Option 2
Provide students with a simplified topographic map with relief and stream systems identified. Students outline and highlight the streams, locate the basin divide, and draw in the basin boundaries. Finally, provide students with a list of possible land uses and ask them to propose sites for them within the basin to minimize impacts on the water supply.

Products from Option 2

- A proposed land-use map on the provided simplified topographic map.

◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆

Option 3
Provide students with a delineated copy of the drainage basin with land-uses (real or hypothetical) indicated on the map. Ask students to consider the consequences of having these activities within the basin and to research and describe how they may affect the water supply. Finally, ask students to consider how the demand for freshwater by their community has affected the landscape and land cover of the area over time (i.e., flooded areas from dam construction, areas cleared for new facilities such as waste water treatment plants, or salinization from irrigation or aquifer draw-down).

Products from Option 3:

- A 2-3 page essay that identifies land-use activities within the drainage basin and their impacts on the water supply. The essay should also address the impacts of water demand on land-cover in the area.

1 The Driving Forces of Global Change

Student Worksheet 1.2

Activity 1.2 Where *Does* My Water Come From?

Have you ever wondered when you turn on the shower just where that water comes from and where it goes when you're done? In this exercise, you will answer that question by tracing your water supply from its source to your faucet and from your drain to its eventual disposal. Knowing where the resources you use daily come from is just one step in creating a "sense of place" or a connection with the environment in which you live. It will also help you see the links between your personal activities and larger scale environmental impacts.

Use whatever sources of information you can find to help you put the pieces of this puzzle together. If you live in a city or municipality, you may need to contact your local water authority. Undoubtedly, there are experts in your community or even at your university who can help you with this exercise. Trace the source as far back as you can (be reasonable!) and be as detailed as possible. Present your results creatively in either a written or poster format. Remember, your water *comes* from somewhere, and it also *goes* somewhere when you're finished with it.

Student Worksheet 1.3

Name:

Activity 1.3 The Water Bill

Exactly how much water do you consume in a day? Do you take long showers? Do you let the water run when you brush your teeth? How much water does it take to run the dishwasher or to flush the toilet? In this activity, you will estimate your daily water usage and compare this to what the average person consumes in other countries of the world.

In the spaces below, list all the activities you do in one day in which you consume or use water. Some activities have already been listed for you. Then, using the data provided in Table 3, calculate how much water each of your daily activities consumes. Total the column to determine your daily usage.

Table 2: My Personal Water Usage

Activity	Times per Day	Total H_2O Usage for Activity
Brushing teeth		
Flushing toilet		
	Total	**Gallons per Day**

Table 3: Typical Household Water Use in the United States

Activity	Estimated Water Usage[4]
Washing clothes in washing machine	53 gallons per load
Flushing toilet	5 gallons per flush
Washing dishes in a dishwasher	22 gallons per load
Washing dishes with tap running	30 gallons
Washing dishes in a filled sink	8 gallons
Running the garbage disposal	4 gallons per minute
Brushing teeth	2 gallons
Shaving with water running	20 gallons
Taking shower with standard shower head	6.5 gallons per minute
Taking shower with low-flow shower head	2.25 gallons per minute
Taking a bath	30 gallons
Washing car with running water	160 gallons per 20 minutes
Washing car with pistol-grip faucet	16 gallons per 20 minutes

Table 4 provides estimates of water consumption in selected countries around the world. Use your data and the data in Table 4 to answer the questions that follow.

Table 4: Per Capita Water Consumption in Selected Countries

Country	Average Daily Consumption (gal/day)[5]	Country	Average Daily Consumption (gal/day)[5]
AFRICA			
Angola	5.8	Botswana	19.3
Egypt	41.6	Kenya	12.6
Mozambique	2.7	Uganda	4.7
Zaire	4.4		
EUROPE			
Albania	4.1	Estonia	76.12
France	77.3	Germany	46.2
Switzerland	28.9	United Kingdom	29.8
NORTH & CENTRAL AMERICA			
Canada	209.4	Haiti	1.2
Jamaica	8.1	Mexico	39.2
United States	176.5		
SOUTH AMERICA			
Argentina	45.4	Brazil	39.3
Chile	70.8	Venezuela	119.3
ASIA			
Iraq	47.4	India	13.3
Israel	47.4	Philippines	89.7
Turkey	101.9	Viet Nam	39.1

---

[4] Data based on Gleick (1993) and Miller (1990). Values have been converted to US units.

[5] Data are derived from WRI (1996). Values have been converted to US units.

BEST COPY AVAILABLE

Questions

1. Compare your own total daily consumption to the per capita daily consumption patterns in selected countries around the world. How does your daily behavior rank in comparison? Where are the highest consumption rates? Where are the lowest?

2. Can you imagine doing all of your daily activities with amount of water that the average person uses in Zaire or Haiti? What daily activities would you give up if you had to live on this amount of water? What would you keep? List them below.

3. Are any uses of water not accounted for in your personal daily estimate? In what other ways do you consume water resources everyday (i.e., indirect uses)?

Optional Activity: Try living on the amount of water than a person in Mozambique would use in one day (2.7 gallons). Fill 3 one-gallon jugs with clean water and use that amount for *all* of your daily activities. You must use this water to bathe, to brush your teeth, to cook, to drink, etc. On your honor, use only this amount of water--no cheating! Record your day, your activities, and your personal feelings in a one day journal entry. What activities did you give up? How did you feel?

1 The Driving Forces of Global Change

Answers to Activities

Activity 1.1 How Many Automobiles? Cars and Consumption

The answers to this activity will vary depending upon the geographic area chosen for consideration. Use the example questions and answers provided in the Instructor's Guide to help initiate class discussion and to calculate totals for your geographic area.

Activity 1.2 Where *Does* My Water Come From?

Results for this activity will vary depending upon the location for which students choose to trace their water source. Overall, the project should be evaluated on the thoroughness of the investigation and the clarity (and creativeness) of its presentation. The following items should be included in the students' written or poster presentation, regardless of the site they choose:

- an identification of the physical source of their water supply, such as a reservoir, river, aquifer, or other source.
- a detailed description of the path that the water takes *from the source to the tap*, including the distance, the method of travel, and any important points along the way (transfer stations, pre-treatment facilities, or storage towers/tanks). A well-researched project would also include a description of what has been added or removed from the water supply.
- a detailed description of the path that waste water takes *from the drain to its ultimate disposal*, including the distance it travels, the method of travel, and important stops along the way (waste water treatment facilities). A well-researched project would also include a description of what has been added or removed from the water supply.

Activity 1.3 The Water Bill

If the instructor chooses to collect the students' calculations of personal daily water usage, they should be evaluated as to whether most activities have been included and whether the calculations are correct. Results will vary among students.

In the responses to the questions on the worksheet, students should (1) compare their daily water consumption to the average daily consumption in other countries, (2) include a list of daily activities that they would keep or give up if they were forced to live on the amount of water that a person uses in Mozambique, and (3) list several indirect uses of water which have not been accounted for in their estimates, such as water used to grow vegetables or produce meat for their consumption, water used to produce the paper they are writing on, etc.

The optional activity could be assigned as "extra credit" in order to encourage participation.

Activity 1.4 Crystal Clear Water

Option 1

This activity should be evaluated on the following criteria:

- the accuracy of the drainage basin delineation
- the extent to which students have identified, located, and characterized the land uses within the basin
- a two-three page essay which explains the types of land use activities in the basin and the impacts that these uses have had on land cover within the basin.

Option 2

The product of this activity (a proposed land-map for a drainage basin) should be evaluated on the following criteria:

- has the water supply been correctly identified?
- has the drainage basin been correctly delineated?
- have all land uses been proposed on the map?
- do the proposed locations of the land uses appear to minimize impacts to the water supply?

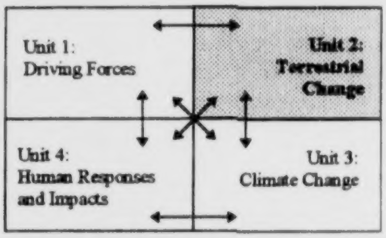
Option 3

The essay that students will write for this activity should be clear and concise, and describe the ways in which land use activities within the drainage basin may affect the water supply and the water quality. There may be both positive and negative impacts. For example, industrial uses within the drainage basin may provide considerable employment for the community, but may also increase water demand and release toxics into the water supply. Students should also consider how the demand for water affects the landscape and land cover of the area. For example, some areas may rely on reservoirs created from dams that have flooded significant amounts of vegetated areas.

In your final evaluation of the projects, consider the skills of the class and their familiarity with this type of exercise. Introductory classes or classes in which students have not been exposed to maps or the concepts of land use and their impacts will require a bit more flexibility than those who are more advanced. See *Notes on Active Pedagogy* for additional suggestions on grading students' written work.

2 Environmental Change In Terrestrial Ecosystems

Background Information



Earth's environment is not static; natural processes are constantly changing it. Some changes, like the movement of tectonic plates, take millions of years and involve things as large as continents. Other changes, such as the creation of a new river bed during a flash flood, are quite localized and take place in minutes or hours. In addition to these processes, human activities also produce changes in nature, some of which accumulate to become globally pervasive. This unit focuses specifically on the human-induced changes to land-based **ecosystems**, including forests, deserts, grasslands, or croplands. Collectively, these ecosystems are known as **terrestrial ecosystems**.

Changes in terrestrial ecosystems are often divided into two broad categories -- changes in **land cover** and changes in **land use**. Land cover denotes the physical state of the land including the quantity and type of surface vegetation, water, and earth materials (Meyer and Turner 1994). Land use describes the human employment of the land, including settlement, cultivation, pasture, rangeland, and recreation, among others (Meyer and Turner 1994).

The rate and magnitude of human-induced change of terrestrial ecosystems have increased through time, although European colonial expansions, the industrial revolution, and the post-World War II era stand out as periods of particularly high rates of human-induced terrestrial change. These periods of pronounced change are associated with, but not limited to, cropping and livestock expansion, land-use intensification, and urban influences in general. Table 5 illustrates the changes in several terrestrial ecosystems, including forests and woodlands, grasslands and pastures, and croplands, for North America and the world.

These global trends, of course, mask major variations by time and place. Richards (1990), for example, suggests that from the beginning of the modern era "agricultural expansion, forest clearing, wetland drainage, irrigation of grasslands, expansion of human settlement, and similar processes have traced a spiraling arc that is determined, for the most part, by European political and economic control." Richards has thus illustrated the extent to which terrestrial change is determined, in part, by global and regional economic and political structures. More recently we might trace variations in the trends of terrestrial change to the vagaries of international markets (production and consumption) and the locations of large-scale population growth.

BEST COPY AVAILABLE

Table 5: Patterns of Terrestrial Change

Region	Vegetation Type	Percent Changes from:				
		1700 to 1850	1850 to 1920	1920 to 1950	1950 to 1980	1700 to 1980
North America	Forests and Woodlands	-4.4%	-2.8%	-0.5%	0.3%	-7.3%
	Grasslands and Pasture	-0.1%	-11.3%	-2.7%	0.1%	-13.7%
	Croplands	1566.7%	258.0%	15.1%	-1.5%	6666.7%
World	Forests and Woodlands	-4.0%	-4.8%	-5.1%	-6.2%	-18.7%
	Grasslands and Pasture	-0.3%	-1.3%	0.5%	0.1%	-1.0%
	Croplands	102.6%	70.0%	28.1%	28.3%	466.4%

Source: Turner et al. 1990. *The earth as transformed by human action.*
©1990 Reproduced with the permission of Cambridge University Press.

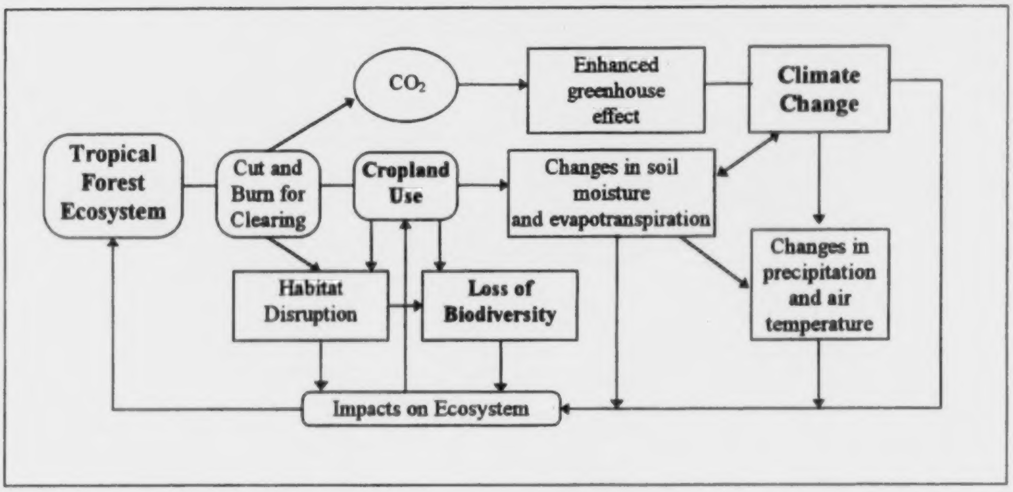
Changes in terrestrial ecology are important in their own right. They affect the **biodiversity** of an ecosystem, that is to say, the number of plant and animal species that can live in an ecosystem. Changes in the structures and functions of ecosystems can affect their fragility and resilience and thus the sustainability of our use of land resources. Changes in terrestrial ecosystems also have important links to climate change because land cover acts as a source and a sink of greenhouse gases. Land cover and land use also determine the amount of reflected versus re-radiated energy the atmosphere receives. (These links to climate change will become clearer in Unit 3.)

Tropical deforestation for ranching and cropping illustrate these complex linkages. When deforestation occurs in tropical areas, the most biotically diverse land cover on earth is replaced with biotically impoverished ones. The cutting and burning of the forest to clear the land for human use releases carbon dioxide into the atmosphere, contributing to the **greenhouse effect** (see Unit 3), while cropping itself releases carbon stored in the soils. In addition, soil moisture and the quantity of **evapotranspiration** in the area are changed, affecting precipitation levels and soil and air temperatures. Changes in soil carbon, local precipitation, and temperatures, in turn, affect the productivity and costs of ranching and cropping. Finally, the newly created ecosystems disrupt the habitats of some species and often provide opportunity for invasive species to thrive.

There is yet one more link to consider -- terrestrial ecosystems are also affected by global climate change. Vegetation and climate are closely linked -- so much so that climate classifications sometimes infer vegetation types. For example, one of the most widely used climatic classification systems is the Köppen System, developed by Wladimir Köppen in the early twentieth century. Though it is an empirical classification based on average temperature and precipitation statistics, Köppen's climatic regions were formulated to coincide with well-defined vegetation regions (Gabler, Sage, and Wise 1991). His climatic classifications make the links between climate and terrestrial ecosystems clear. If climates change, so too will vegetation patterns and the pattern of ecosystems across the earth.

The diagram in Figure 4 illustrates some of the complex links that exist between terrestrial change and other forms of environmental changes, including climate change.

Figure 4: Links Between Terrestrial Change and Other Forms of Environmental Change


CO$_2$
Enhanced greenhouse effect
Climate Change
Tropical Forest Ecosystem
Cut and Burn for Clearing
Cropland Use
Changes in soil moisture and evapotranspiration
Changes in precipitation and air temperature
Habitat Disruption
Loss of Biodiversity
Impacts on Ecosystem

BEST COPY AVAILABLE

2

Environmental Change in Terrestrial Ecosystems

Instructors Guide to Activities

Goal

Students are introduced to terrestrial change as one form of environmental change. Students will be able to understand land-use/cover change and to assess it from a variety of data sources.

Learning Outcomes

After completing the exercises associated with these activities, students should be able to:

- understand the concepts of terrestrial change, including land-use/cover change;
- recognize the link between climate and vegetation;
- construct and interpret a scatterplot;
- collect and use various qualitative data sources;
- "read" and compare satellite images and GIS maps for spatial and temporal variations; and
- link land-use/cover changes to driving forces of global change.

Choice of Activities[6]

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select those that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

2.1 Vegetation Cover -- Plotting bi-variate data, and analysis/ interpretation of results
2.2 Satellite and GIS Images of Terrestrial Change -- Identification of terrestrial change in satellite imagery and GIS outputs
2.3 Fiction and Fact: Terrestrial Change in Film -- Analysis of film for portrayals of land-use/cover change
2.4 Our Town: A Historical Reconstruction of Terrestrial Change -- Use of qualitative data sources to identify changes in land-use/cover over time.

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

---

[6] For additional active learning materials and activities on land-use/cover change, see another module in this series *Human driving forces and their impacts on land-use/land cover* (Moser 1996).

- Background Information to Unit 2 (all students should read)
- Goldsmith, E., N. Hildyard, P. McCully, and P. Bunyard. 1990. *Imperiled planet: Restoring our endangered ecosystems*. Cambridge: MIT Press, pp. 54-96 (*Forests*).
- Meyer, W.B. and B.L. Turner II, eds. 1994. *Changes in land use and land cover: A global perspective*. Cambridge: University Press, Chapters 2-4.
- ________. 1992. Human population growth and global land-use/cover change. *Annual Review of Ecology and Systematics* 23: 39-61.
- Turner, B.L, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds. 1990. *The earth as transformed by human action*. New York: Cambridge University Press, Chapter 10.

Activity 2.1: Vegetation Cover

Goals

Students use basic quantitative data to understand the relationship between climate and vegetation.

Skills

- ✓ plotting bi-variate data
- ✓ bi-variate data interpretation

Material Requirements

- *Student Worksheet 2.1* (provided)
- graph paper or computer-based spreadsheet software
- vegetation and precipitation data (provided in *Supporting Materials 2.1*)

Time Requirements

One class period (50 minutes) if done in class. Activity can also be assigned as homework.

Tasks

Students plot data on vegetation cover and precipitation in order to identify the type of relationship that exists between the two variables. Students will then use the results of the scatterplot to answers questions about the relationship between the variables and to predict what would happen to vegetation cover if precipitation amounts were affected by environmental change.

This activity is primarily geared toward students who have relatively little experience with analyzing and interpreting quantitative data. To adapt this activity to a higher skill level, consider the following options:

- Instead of providing students with the data in *Supporting Material 2.1*, ask them to find, plot, and interpret their own data relating a climatic variable (e.g., precipitation, temperature, etc.) to vegetation cover (e.g., type, coverage).

- Ask students to find and analyze other types of variables related to vegetation cover. For example, students can research country-level data on decreases in forest, savanna, or wetland land covers and relate these changes to another variable such as GNP, total external debt, or increases in agricultural production (all of these data are easily obtained through the most recent volume of *World Resources* published annually by World Resources Institute).

Activity 2.2 Satellite and GIS Images of Land Cover Change

Goals

Students become familiar with two methods that geographers use for assessing global environmental changes -- satellite imagery and Geographic Information Systems -- and use these data sources to detect spatial and temporal changes in land use and land cover.

Skills

- ✓ use of remotely sensed data
- ✓ interpretation of satellite and GIS images
- ✓ essay writing

Material Requirements

- *Student Worksheet 2.2* (provided)
- Background information on tropical forests (*Supporting Material 2.2*)
- Satellite images illustrating land use/cover change (Black and white satellite imagery illustrating changes in land cover in Amazonia are provided in *Supporting Material 2.2a*)
- GIS land-cover maps produced from satellite imagery illustrating changes in land cover (Black and white maps provided in *Supporting Material 2.2b*)

Time Requirements

One class period (50 minutes) for in-class portion, with additional time for students to prepare written assignment.

Data Sources

- The satellite images provided in *Supporting Material 2.2a* were taken from the WWW site of the Instituto Nacional de Pesquisas Espaciais (National Institute of Space Research) in Brazil: http://www.inpe.br/grid/quick-looks. You can explore their homepage at http://www.inpe.br.

- Excellent time-series Landsat images of deforestation in Rondonia, Brazil (3 images, 1975, 1986, and 1992) are available at minimal cost through the following:

  Eros Data Center Distributed Active Archive Center User Services, US Geological Survey
  EROS Data Center
  Sioux Falls, SD 57198
  Tel: 605-594-6116 Fax: 605-594-6963
  Email: edc@eos.nasa.gov WWW: http://edcwww.cr.usgs.gov/landdaac

- For a catalogue of additional images and datasets available through the United Nations Environmental Information and Assessment Programme, contact:

  Regional Coordinator -- North America
  UNEP Environmental Information and Assessment Programme
  EROS Data Center
  Sioux Falls, SD 57198
  Tel: 605-594-6117 Email: grid@grid1.cr.usgs.gov
  Fax: 605-594-6119 WWW: http://grid2.cr.usgs.gov

- See *Appendix A* for additional World Wide Web sites where satellite images may be available.

Tasks

Students will use satellite and GIS images to detect spatial and temporal changes in land cover. The satellite images provided in *Supporting Material 2.2a* depict two different areas in Amazonia taken at the same point in time, illustrating spatial variations in land cover. The GIS maps provided in *Supporting Material 2.2b* depict the same area in Thailand for two different points in time, illustrating temporal changes in land cover. Because black and white images may be more difficult to interpret, instructors may want to provide color satellite images which can be obtained from the above sources. Instructors may be able to obtain color GIS images in their own institution's cartography/GIS laboratory.

Based on information gathered in background reading and in observation of the images provided, students write short responses to several questions on the student worksheet. As a homework assignment, students write a longer essay in which they will assume a role based one of two scenarios provided.

Activity 2.3 Fiction and Fact: Terrestrial Change in Film

Goals

Students identify the ways in which land-use/cover change and other human-induced impacts to the environment are portrayed in film.

Skills

✓ film interpretation
✓ essay writing in movie review format

Material Requirements

- Film or video of one of more of the following titles (other titles may be used at instructor's discretion):

  The Emerald Forest *The Good Earth*
  Lawrence of Arabia *Grapes of Wrath*
  The Killing Fields *True Stories*

Time Requirements

One or two class periods (50-100 minutes) if the film is shown in class and the written work is assigned as homework. If the activity is assigned entirely outside of class, it should take about 15 minutes to introduce and explain it. Students should be allowed ample time (7-10 days) to access the film, to view it, and to prepare their essay.

Tasks

Students view one of the selected movies with a list of questions to consider during the film (see below). Instructors may choose one film for all students to view or allow students to select a film of their choice. After watching the film, students write a 2-3 page movie review of the film that underscores the movie's portrayal of land-use/cover change. Student will then present their review to the class in a "Siskel and Ebert"-style debate regarding the ability of the movie to portray land-use/cover change effectively and discuss how these portrayals can be linked to global change.

Instructors should preview the selected movie that the students will watch. The movie can either be shown in class or placed on reserve for students to access on their own time. In addition, students can be given the option of renting the film at their own convenience. Most of these films are popular and should be available at local video rental stores. In a large class, you may wish to provide students with several movie options.

As you preview the film, identify key elements of land-use/cover change in order to have an idea of what the students should provide in their essays. Students will consider the following key questions when viewing the film and preparing their reviews:

1. What images of land-use/cover change and/or other human-induced environmental impacts are portrayed in the film?
2. When do these images occur in terms of plot and dramatic development?
3. What are the land-use/cover changes in the movie?
4. How did human activity contribute to land-use/cover changes?
5. How did people respond to these land-use/cover changes?
6. How do land-use/cover change and human-induced environmental impacts change in the movie?
7. Do the portrayals underscore actual change in the land uses or land covers portrayed? For example, are rice paddies actually being transformed in the *Killing Fields*? Are forest really being cleared in the *Emerald Forest*?
8. Do the portrayals underscore symbolic changes in the development of the drama? For example, do the images of mountains in the *Killing Fields* indicate promise of Dith Pran's escape?

Activity 2.4 Our Town: A Historical Reconstruction of Terrestrial Change

Goals

Students are introduced to the use of qualitative data sources for identifying elements of terrestrial change. The activity helps students interpret different types of qualitative data and develop skills of analysis that will allow them to make generalizations about land-use/cover changes in historical contexts.

Skills

✓ collection of qualitative data
✓ assessment of biases in qualitative data
✓ interpretation and contextualization of qualitative data
✓ resolution of conflicting data/accounts
✓ data presentation

Material Requirements

- *Student Worksheet 2.4* (provided)
- Option I: Repeat photographs of Dust Bowl period (or other photos illustrating changes in land use/cover).
- Option II: Access to the following historical data:
  - local newspaper with a regular coverage of the past 100 years
  - local residents who have lived there for at least 30 years
  - photographic collections of local area with data as far back as possible
  - local written accounts such as diaries, journals, and travel logs
  - post-card images of the area or town (if available--try antique stores)

Additional Readings and Resources for the Instructor

- Ellen, R.F. ed. 1984. *Ethnographic research: A guide to general conduct.* Orlando: Academic Press.
- Pile, Steve. 1992. Oral history and teaching qualitative methods. *Journal of Geography in Higher Education* 16(2), p. 135.
- Rogers, Garry F. 1984. *Bibliography of repeat photography for evaluating landscape change.* University of Utah Press.
- Tierney, William G. 1994. Teaching qualitative methods in higher education. *Review of Higher Education* 17 (Winter).

Time Requirements

Option I: 1-2 class periods (50-100 minutes)

Option II: 2 or more class periods (100+ minutes), plus several weeks of group work outside of class

Tasks

Option I
Students analyze repeat photographs of the Dust Bowl period. Photos have not been provided, but are easily accessed by the instructor for classroom use (see resources above). If you do not wish to focus on the Dust Bowl, you can select other photos that illustrate significant changes in land use/cover over time (e.g., agricultural to urban, forests to agricultural, etc.). The student worksheet is written for use with any set of photos.

As individuals, or in small groups, students answer the questions on the student worksheet and write a one-page memo as a consultant to Soil Conservation Service about the possible human causes of the changes identified. To wrap up the activity, hold a "Dust Bowl Policy Conference" to discuss the individual or group findings. The Conference may be just a group discussion or a more formal process where the groups present their findings to the class. During the conference, students should discuss the power and limitations of this type of analysis and the type of data as a source of information.

Option II
The product of this activity may be a museum-quality exhibit to be displayed at the undergraduate library, the departmental showcase, the public library, or some other public venue.
Students collect qualitative information on historical changes in land-use/cover for a particular study area (i.e., the local city, county, or other area of interest) that illustrates or provides evidence for (1) terrestrial change in the study area, (2) the human driving forces of terrestrial change, and (3) the effects of terrestrial change on humans and the human responses to such change.

To begin, divide the class into groups based upon the different types of data to be explored. You can use the 6 groups below as a guide.

Group A: Photographic Collections of the Study Area
Group B: Oral Histories of the Study Area
Group C: Newspapers and Public Texts of the Study Area
Group D: Personal Diaries and Travel Logs (Semi-private accounts) of Study Area
Group E: Maps and Map Collections of Study Area
Group F: Fictional Accounts and Art of the Study Area (optional)

Allow students to choose the type of data they would like to work with (if feasible). Some students may prefer to work with archival data, while others may prefer to interview people. A very shy person may be intimidated by collecting oral histories. The point of this exercise is to demonstrate not only the way that certain data sources come together to create a "big picture," but also to demonstrate how certain methods of working collaboratively can help develop a whole project.

As each group begins its data collection, each person should carefully record her/his sources and reference them so that they can be located again. Each person in the group will write a 2-3 page summary (with references) of the information they have found and how it relates to 3 general study questions about terrestrial change listed above. Each student will submit this summary to their group for consideration.

Once all the data have been collected, each group should discuss the strengths and weaknesses of their data source. What does it offer and what does it leave out? Do you have to get special permission to use the data? Do you need written consent to record an interview? Do you need special equipment to photocopy a map? Each group will write a 1-2 page working paper on the biases of their data sources that should be made available to all groups.

Finally, each group prepares samples of their findings in a form that can be used in a museum exhibit or poster session (i.e., photographs, photocopies of newspaper accounts, excerpts from oral histories, copies of hand-written diary accounts, copies of maps). Investigate the possibility of displaying this exhibit in a public location within the community, the University, or within the department.

2 Environmental Change in Terrestrial Ecosystems

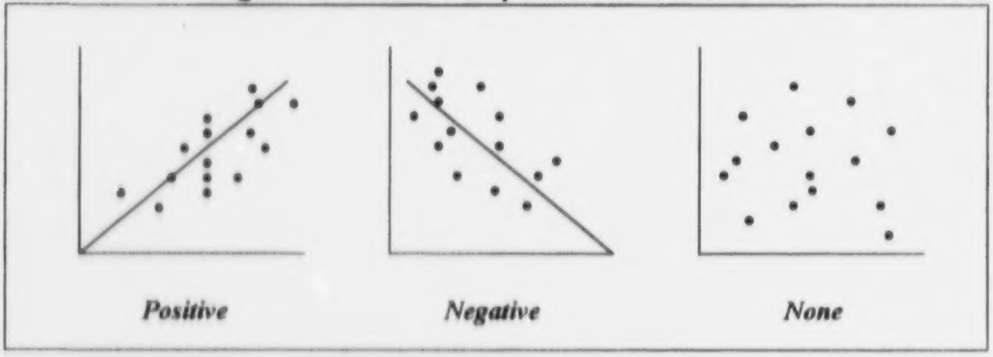
Student Worksheet 2.1

Activity 2.1 Vegetation Cover

The data presented in this exercise represent thirty different stations from geographically diverse areas around the world. At each of these stations precipitation and vegetation cover (in percent) were measured once per station at the same time of year. The purpose of this exercise is to determine whether there is a relationship between vegetation cover and precipitation amount.

One way to identify a relationship between two variables, like vegetation cover and precipitation, is to plot those variables on a graph called a ***scatterplot***. If the data graphed in the scatterplot cluster around an imaginary line that is not horizontal, the variables are related in that a change in the value of one variable (e.g., precipitation) means a change in the value of the other (e.g., vegetation). An imaginary line that slopes up and to the right indicates that there is a *positive relationship* between precipitation and vegetation cover: where there are high levels of rainfall, we would expect to find a lot of vegetation cover, and where rainfall is low, we would expect vegetation cover to be sparse. An imaginary line that slopes down and to the right indicates that there is a *negative relationship* between precipitation and vegetation cover. In this case, we would expect high levels of vegetation in areas of low rainfall. Lastly, if the points on the graph are randomly dispersed and do not show a clear slope up or down, it would indicate that there is no clear relationship between precipitation and vegetation. If there is no relationship, we cannot make any predictions about how much vegetation cover we would expect to find in an area with a certain rainfall level. For example, for any given precipitation level, a wide range of amount of vegetation cover could be possible. The three graphs in the figure below illustrate these relationships.

Figure 5: Relationships Between Variables



Positive *Negative* *None*

By looking at the scatterplots, we can also determine the "strength" of the relationship between the variables. If the points are tightly clustered around the imaginary line, the relationship between the variables is relatively strong; that is, for any precipitation value, there is a small range in the amount of vegetation cover observed: in this case, precipitation is a pretty good predictor of vegetation cover. If the points are widely scattered but still appear to cluster around an imaginary line, the relationship is relatively weak.

Using a sheet of graph paper or a computer-based software program, create a scatterplot of the precipitation and vegetation cover data provided by your instructor. Label the y-axis of your graph "vegetation" and the x-axis "precipitation." Locate each of the 30 stations on the graph. Finally, answer the following questions.

1. Does your scatterplot suggest that there is a relationship between precipitation and vegetation cover? If so, what is the relationship?

2. Is this relationship strong or weak? How does this affect your ability to predict change in vegetation cover as a function of a change in precipitation?

3. What other factors control vegetation growth in addition to precipitation?

4. If global climate changes caused a decrease in precipitation in some of the wetter areas in the data set, what would you expect to happen to vegetation cover? What would happen to the vegetation cover if precipitation increased in the drier areas?

5. Is the relationship you've identified really linear (that is, can you see a non-linear trend in the data at higher levels of precipitation and vegetation cover)? If the relationship is not linear, then how accurate were your previous predictions?

6. Based on your answer to Question #2, what would be the indirect effects from a change in precipitation leading to a change in vegetation cover? Come up with as many human and natural systems as you can think of that would be indirectly affected by such a change.

Student Worksheet 2.2 Name

Activity 2.2 Satellite and GIS Images of Terrestrial Change

Aerial photos and satellite images are tools that geographers use to gather information about the earth. Gathering information through satellites or aerial photography is called **remote sensing**. Remote sensing simply means that information about an object has been gathered without the observer ever coming in contact with the object of study. For example, by placing your hand above a warm stove burner, you can discover that the stove is hot without ever really touching it. In a similar way, geographers can learn what is happening on the surface of the earth, and sometimes even below it, by using images collected by satellites orbiting the planet. Such imagery can be especially useful in identifying many forms of environmental change including land-cover change.

A Geographic Information System (GIS) is another tool for assessing environmental change. A GIS is a computer-based technology that allows geographers to analyze, manipulate, and display geographic information, like that gathered by satellites and transmitted to earth. In essence, a GIS is a combination of computer cartography and database management that allows geographers to solve problems that require large amounts of data.

In this activity, you will use both remote sensing and GIS tools to explore terrestrial change.

Part A: Satellite Images

Look at the two satellite images provided by your instructor. These are images of different areas taken at the same point in time. After you have studied the two images, answer the following questions:

1. In which image is a land-use/cover change apparent?

2. What evidence suggests that a land-use/cover change has occurred?

3. Is there any evidence to suggest that the land-use/cover change was human-induced? If so, what is the evidence?

Part B: GIS Images

Next, look at the two GIS images provided by your instructor. These images represent the same area but at two different points in time. Study the images and answer the following questions:

1. What evidence do you see of land-use/cover change?

2. In what ways do the images differ from the satellite images? How does this affect their usefulness?

Part C: Tropical Forest Essay

For homework, write a 2-3 page essay assuming the role outlined in one of the scenarios listed below. Before writing your essay, you may need to do some additional research to help better understand the complex forces leading to degradation of tropical rainforests. Some basic statistics on rainforest development have been provided for you in *Supporting Materials 2.2*. If you have access to the World Wide Web, you may want to visit the Rainforest Action Network Home Page at the following address: http://www.ran.org/ran/info-centers/rates.html.

Scenario 1: You are a member of the Amazon Preservation Commission. You have heard of a proposal to build a hydroelectric plant and access road on a tributary of the Amazon River. As a member, prepare a 2-3 page report to the board of the Commission outlining the potential impacts of the project and proposing a plan to present to developers to minimize forest destruction impacts on indigenous peoples.

Scenario 2: You are a member of the Tupi tribe (the largest in Brazil), and you've heard of the proposal to begin construction of a hydroelectric plant and access road on the river within a mile of your home. No one has come to you or your tribe and explained the proposed construction or the effect it will have on your tribe. As an elder in the tribe, it is your task to tell a representative from the UN how this project will affect you and your tribe.

Student Worksheet 2.3

Activity 2.3 Fiction and Fact: Terrestrial Change in Film

In this activity, you will watch a film selected by your instructor and write a short movie review essay. The purpose of this exercise is to identify examples of land-use/cover change and associated human-induced impacts. As you watch the film, be sure to consider the following questions:

1. What images of land-use/cover change and/or other human-induced environmental impacts are portrayed in the film?
2. When do these images occur in terms of plot and dramatic development?
3. What are the land-use/cover changes in the movie?
4. How did human activity contribute to land-use/cover changes?
5. How did people respond to these land-use/cover changes?
6. How do land-use/cover change and human-induced environmental impacts change in the movie?
7. Do the portrayals underscore actual change in the land uses or land covers portrayed? For example, are rice paddies actually being transformed in the *Killing Fields*? Are forest really being cleared in the *Emerald Forest*?
8. Do the portrayals underscore symbolic changes in the development of the drama? For example, do the images of mountains in the *Killing Fields* indicate promise of Dith Pran's escape?

In addition to these questions, be sure to note who made the movie, when it was made, and its basic plot. You may want to watch the movie twice -- once for enjoyment and a second time with a keen focus on answering these questions.

The Movie Review

Write a 500-750 word (2-3 double-spaced pages) movie review of the film. You may want to look at current movie reviews in a popular entertainment magazine or in the newspaper to incorporate the flavor of this writing style into your review. Do not read reviews of the movie you watched! This may add another layer of interpretation to your analysis.

In your review, include answers to the questions that you considered during the film. Be sure to include your understanding of the movie's portrayal of land-use/cover change in terms of actual terrestrial change, as well as symbolic change used to highlight a dramatic moment.

In the next class period, be prepared to present your review in a "Siskel and Ebert-type" debate during which you discuss the movie's ability to portray land-use/cover change effectively and whether the land-use/cover change is linked to global environmental change.

Student Worksheet 2.4 Name ______________________

Activity 2.4 Our Town: A Historical Reconstruction of Terrestrial Change (Option I)

1. Look at the photos provided by your instructor and record the following information:

   When was each photo taken? ______________________

   Where was each taken? ______________________

   What is the time interval between each pair of photos? ______________________

2. Make a list of visible patterns in the terrestrial environment for each picture. Include vegetation, soil texture, moisture. Are human features visible in the pictures?

Photo A	Photo B	Photo C

3. What are some of the changes in the terrestrial environment that you can see in the photos?

____

____

____

____

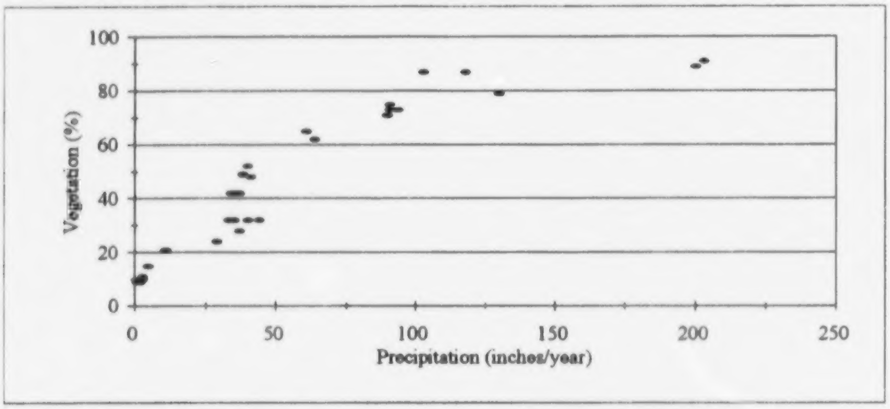
4. You have been hired by the Soil Conservation Service to make a short report on the possible driving forces responsible for these changes. Draft a one-page memo on the biophysical components (climate, soil changes, vegetation changes) as well as the human driving forces you think may be responsible for the changing patterns you've identified.

2 Environmental Change in Terrestrial Ecosystems

Answers to Activities

Activity 2.1 Vegetation Cover

Students should produce a graph that resembles the one pictured below. Students may produce the graph manually or with a computer-based spreadsheet software.



The answers below should be used as a guide for evaluating students' responses to the questions posed on the student worksheet.

1. The scatterplot indicates a positive relationship between vegetation cover and precipitation.
2. The relationship between vegetation cover and precipitation appears to be relatively strong. A strong relationship allows me to predict fairly accurately the amount of vegetation cover as a function of precipitation.
3. Other factors include temperature, soil conditions and fertility, topography, length of day (latitude), and altitude, among others.
4. A decrease in precipitation would most likely result in a decrease in the percentage vegetation cover. An increase in precipitation would most likely increase the percentage vegetation cover.

5. The relationship appears to be linear until about 110 inches/year of precipitation, where the relationship levels off. This suggests that beyond this point additional precipitation does not produce an increase in vegetation cover.

6. An increase or decrease in precipitation will affect the vegetation cover in many ways. If an increase in precipitation occurs, only those plants that can withstand the additional moisture will survive. If a decrease occurs, only those plants that can withstand the drier conditions will survive. In both cases, the changes will affect various human and natural systems. For example, precipitation changes will have impacts on virtually every terrestrial ecosystem and may result in a shift to a different land cover. Precipitation changes will also affect the ways in which humans can use the land. Farmers may have to alter the types of crops they plant, timber companies may have to migrate, gardeners may have to change their backyard crops, etc.

Activity 2.2 Satellite and GIS Images of Terrestrial Change

The answers below should be used as a guide for evaluating students' responses to the questions posed on the student worksheet. If you have used your own images rather than those provided, responses will vary.

Part A: Satellite Images (using the images of Amazonia provided in *Supporting Material 2.2a*)

1. Deforestation is apparent in Image B.

2. The lighter colors and the geometric shapes on Image B indicate a change in land cover.

3. The geometric shapes indicate that the changes were human-induced.

Part B: GIS Images (using the images of Thailand provided in *Supporting Material 2.2b*)

1. The increased portion of light shading in the image of Time B is evidence of a land cover change.

2. The GIS images are more coarse, meaning the image shows less detail. It also shows only two classifications. The coarse spatial resolution means that we can't be as precise in delineating areas of deforestation.

Part C: Tropical Forest Essay
The essays for this exercise will vary based the scenario chosen. Students should write a clear and concise essay that reflects some additional research on their part. Be certain that students have followed the assignment and that their essay reflects their assumed role and is directed at the

proper "audience." See *Notes on Active Pedagogy* for additional suggestions on assessing students' written work.

Activity 2.3 Fiction and Fact: Terrestrial Change in Film

The essays for this exercise will vary based on the film chosen for review. Use the criteria below to evaluate the essays. See *Notes on Active Pedagogy* for additional suggestions on evaluating students' writing.

- Does the student demonstrate an understanding of land-use/cover change within the filmmaker's portrayal?
- Does the student address all or most of the eight questions that they were asked to consider while viewing the film?
- Is the essay well-written and in a movie review format?

The presentation of the essays should be in the form of a "Siskel and Ebert style" debate. The debate should be informal and fun, but students should be able to clearly articulate their review of the movie and its portrayals of land-use/cover change.

Activity 2.4 Our Town: A Historical Reconstruction of Terrestrial Change

Option I

The answers to the questions on the student worksheet will depend on the photos that the instructor chooses for the exercise. The students' one-page memo should demonstrate an understanding of driving forces and their connections to terrestrial change.

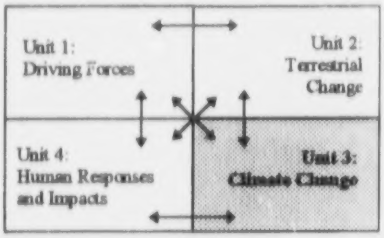
Option II

Evaluation of this long-term project is left to the discretion of the instructor. The structure and results of the exercise will vary based on the size of the class, the amount of time allotted, and the availability of multiple data sources.

3

Climate Change

Background Information



As explained in previous units, global environmental change refers to both human-induced and natural transformations of all of the earth's systems. Yet the popular perception of this change is focused largely on climate change, especially global warming. In this regard, it is important to distinguish between **climate and weather**. Essentially, weather refers to the condition of the atmosphere at any particular time and place (e.g., What is the temperature today? Is it raining or snowing? What is the humidity and air pressure?) Climate, however, refers to the long-term characteristics of the climatic system for the area (e.g., What is the average temperature? Is the area generally prone to drought or to tropical storms? What is the annual average rainfall?).

Climate change is not a new phenomenon. In fact, the earth has undergone significant variations in climate during its estimated 5 billion year life. Cold periods known as ice ages put parts of the earth under glaciers for hundreds of thousands of years. Of particular concern today is a warming of the earth's climate, occurring more rapidly than any of the previous climate changes that the earth has experienced. Unlike previous climate changes, however, this global warming has a very clear human component.

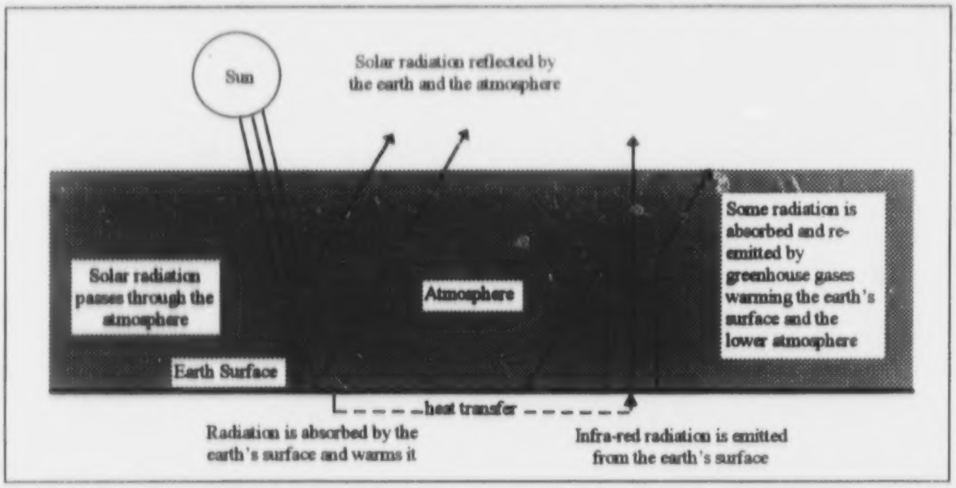
Global Warming and the Greenhouse Effect

The earth's atmosphere consists primarily of nitrogen and oxygen, and a small amount of trace gases known as **greenhouse** gases, which include water vapor, carbon dioxide, methane, and nitrous oxide. These greenhouse gases act much like the panes of glass in a greenhouse, allowing short-wave energy from the sun to pass through them, but trapping the longer-wave heat radiation that is radiated back to the atmosphere from the earth's surface. This **greenhouse effect** is a vital atmospheric process without which the earth would be a cold and lifeless planet (see Figure 6).

Human activity has begun to alter the composition of the earth's atmosphere. The by-products from industrialization, such as carbon dioxide from the combustion of fossil fuels like coal and oil, have augmented the amount of greenhouse gases in the atmosphere. This is known as the **enhanced greenhouse effect**. An increase in greenhouse gases traps additional heat energy within the atmosphere and is predicted to result in an increase in the annual average temperatures on earth.

BEST COPY AVAILABLE

Figure 6: The Earth's Atmosphere and the Greenhouse Effect


Sun
Solar radiation reflected by the earth and the atmosphere
Solar radiation passes through the atmosphere
Atmosphere
Some radiation is absorbed and re-emitted by greenhouse gases warming the earth's surface and the lower atmosphere
Earth Surface
heat transfer
Radiation is absorbed by the earth's surface and warms it
Infra-red radiation is emitted from the earth's surface

Source: Adapted in part from IPCC. 1990. *Climate Change: The IPCC Scientific Assessment*. Houghton, Jenkins, and Ephraums, eds. Cambridge: Cambridge University Press, pp. xiv.

Climate change resulting from human activity is much more complex than just the rise in **global annual mean temperature** (the average temperature per year for the entire planet) that is predicted by the end of the next century. This unit will examine some of the research that is being undertaken in order to gain some understanding of the nature and magnitude of future climatic variability.

The Intergovernmental Panel on Climate Change (IPCC, an international committee composed of hundreds of leading scientists), has made the following predictions about the future of the earth's climate (IPCC 1996a):

- a doubling in atmospheric carbon dioxide levels by 2100;
- a rise in global annual mean temperature of 2°C by 2100 (with a range of between 1° and 3.5°C);
- an increase in sea level of 50 cm by 2100 resulting from thermal expansion of oceans and melting of glaciers and ice sheets (with a range between 15 and 95 cm);
- a more vigorous hydrological cycle, meaning the potential for more severe droughts and/or floods in some areas, and an increase in precipitation intensity, suggesting the possibility of more extreme rainfall events.

Scientists have predicted that the rise in the global mean annual temperature will affect the frequency of extreme weather events such as hurricanes, typhoons, tornadoes, severe storms, and floods. When the atmosphere gets warmer, more water evaporates from the oceans, and in turn, more rain and snow fall from the atmosphere. The extra energy released with this evaporation and precipitation cycle increases the power of storms. Water vapor also contributes to the

BEST COPY AVAILABLE

greenhouse effect and could create what scientists refer to as a **positive feedback,** meaning that the processes of warming and evaporation will continue to intensify and feed off each other increasing the rate and magnitude of the effect (in this case, temperature rise).

Climate change will also affect the amount and timing of precipitation. Warrick and Farmer (1990) note that small variations in mean precipitation could result in large changes in the risk of extreme weather events such as drought and severe tropical storms. Pierce (1990) hypothesizes that climatic variability will almost certainty affect the timing and intensity of the monsoon seasons upon which millions in Africa and Asia depend for agricultural productivity.

Thus, it is fairly certain that climate change will have important impacts on the global environment and the world's population. It is also clear that some populations may be more vulnerable to the effects of global climate change than others. For example, in lesser developed parts of the world, increased frequency of droughts could have devastating effects on crop yields and food supply; sea level rise could increase the risk of flooding to settlements in marginal coastal areas. These same events may not have equivalent impacts on the more developed parts of the world where people may be able to afford preventative or mitigative measures or even to accommodate some amount of environmental change.

For this reason, it is important to have the best possible information on the likelihood of the intensity and regional nature of climate change in order to prepare for or mitigate some of the effects of such change. But how do we go about predicting these changes? Scientists are working on improved models of the operation of the atmosphere that allow more sensitive and robust assessments of different scenarios in which climate change will take place (e.g., assessments that have a better understanding of the relationship between vegetation characteristics and precipitation illustrated in Activity 2.1.) Two basic areas of modeling research are currently active -- analogue models and general circulation models.

Climate Models

Analogue models

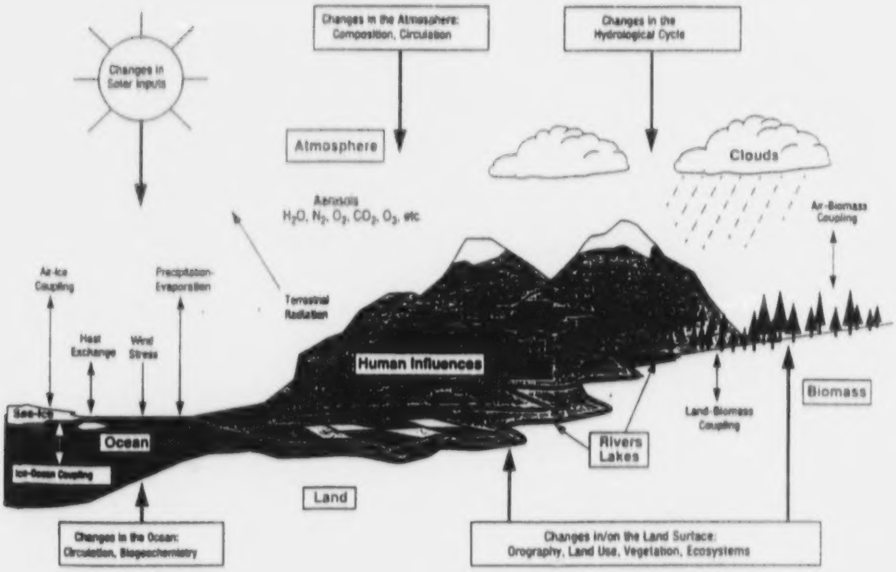
Broadly, analogue measurement is a process through which changes in one phenomenon, such as temperature, are measured through changes in a related or "analogous" phenomenon, such as expansion and contraction of mercury in a thermometer. An analogue model extrapolates the dynamics of climate change from *actual* data that have been collected and measured (i.e., parts per million of atmospheric dust or millimeters of precipitation). Two examples of this kind of research include:

- reconstructing paleoclimatic records or records of past climates using material such as fossilized pollen samples (palynology), ocean sediments and polar ice;
- intensive analysis of regional climatic conditions during warm years (to obtain, for example, data concerning the response of growing season parameters)

General Circulation Models

General Circulation Models (GCMs) are extremely sophisticated computer models of the earth's climate system. GCMs were designed to help scientists learn about the complexities of the interactions among the atmosphere, the oceans, the lithosphere, and the biosphere. Figure 7 illustrates the complexity of the earth's climate system.

Figure 7: The Earth's Climate System


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
Aerosols
H_2O, N_2, O_2, CO_2, O_3, etc
Air-Biomass Coupling
Air-Ice Coupling
Precipitation-Evaporation
Terrestrial Radiation
Heat Exchange
Wind Stress
Human Influences
Biomass
Sea-Ice
Ocean
Land-Biomass Coupling
Rivers Lakes
Ice-Ocean Coupling
Land
Changes in the Ocean: Circulation, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows), and some aspects that may change (bold arrows). Source: IPCC 1996. ©1996 reprinted by permission of IPCC. Andrew Dlugolecki, *Climate change 1995: Impacts, adaptations, and mitigation of climate change*.

To reproduce exactly such a system in a computer model requires more computer power than is currently available; consequently, a number of strategies have been employed to reduce the computer requirement One strategy is to represent large regions of the earth with *average* climate data. This means that *one* temperature and precipitation value is used to represent several hundred square kilometers. In so doing, much of the spatial variability in temperature and precipitation is obscured. The second strategy is to make predictions without running an enormous number of calculations for hundreds of years. This is accomplished by running the computer models to an equilibrium or balanced state. GCMs are run in the following way:

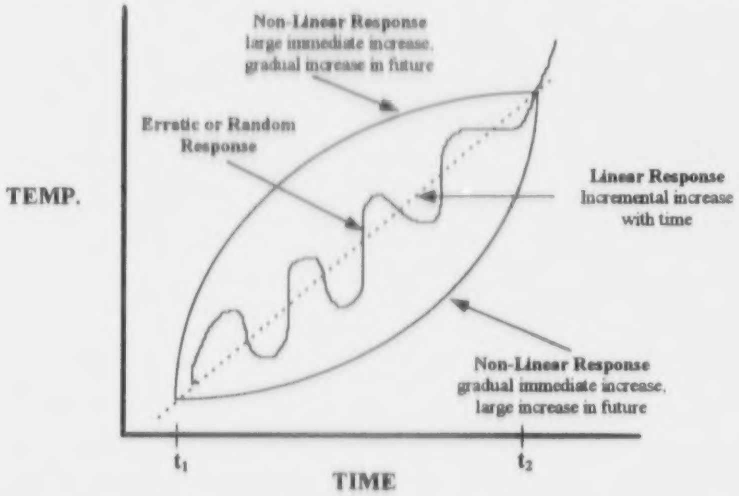
1. Run the GCM under normal conditions until it reaches equilibrium.
2. Change one variable in the model, such as solar output, or the concentration of a greenhouse gas.

BEST COPY AVAILABLE

3. Run the GCM again with the one changed variable until it reaches equilibrium.
4. Compare the results of the second run with the first run to determine what effect the selected variable had on the climate.

There are, of course, several problems with this technique. One is that the modeler begins with an initial temperature solution and ends with a different final temperature solution. By simply comparing the two values, the analyst can determine how much of a temperature change is expected over time. It is impossible, however, to know *how* the temperature change occurred over time. It is easiest to assume that the change in temperature was *linear*, meaning that for every unit of time, the temperature increased an equal amount. But it is unlikely that a linear response will occur because of the complex feedback mechanisms in the climate system. Figure 8 illustrates the variety of temperature responses that could occur between two points in time. The response could be linear, as mentioned above, allowing scientists to estimate a temperature change over a given time period. The response could also be *non-linear*. A non-linear response could mean that temperatures increase rapidly then level off or that they increase slowly at first then rapidly near the end of the period. Finally, the response could be random, meaning that the pattern is unpredictable and erratic.

Figure 8: GCM Temperature Response Scenarios


Non-Linear Response
large immediate increase,
gradual increase in future
Erratic or Random
Response
TEMP.
Linear Response
Incremental increase
with time
Non-Linear Response
gradual immediate increase,
large increase in future
t_1
t_2
TIME

Note: In each case, the same temperature values occur at times 1 and 2, but how the temperature changes over time is not clear: the process could be linear, non-linear, or random.

We are still left with an important question -- what will be the likely temperature scenario? With increased computer power in the last few years, a different approach to climate modeling has been developed. A time-dependent or transient climate model is now a favored technique. Here

BEST COPY AVAILABLE

the computer model increases carbon dioxide concentrations by 1% every year. The model is then run for at least 70 years, when atmospheric carbon dioxide levels are predicted to have doubled.

A direct comparison between the initial conditions and the 70th year will not yield proper climate change figures because of climate model drift. Every GCM simulates the earth differently, and therefore, every model will drift to its own particular climate as the model progresses. To eliminate this problem, another model is run to 70 years without any change in carbon dioxide levels. Then the two model results can be compared.

Numerous transient climate modeling experiments that use different time frames will help scientists predict the likely temperature scenario we will face during the next 100 years. Of course, these models introduce another concern. The rate of greenhouse gas emissions, which is not required in equilibrium climate experiments, becomes important in transient experiments. Thus the human response of reducing or increasing the rate of greenhouse gas emissions is critical in determining what future climate may prevail.

There are several other concerns with using GCMs. It is important to emphasize that the mathematical equations that constitute the mechanisms of the models represent only *approximations* of the climate system. Scientists do not fully understand how all components of the system operate, and only the largest and most powerful computers can handle the levels of processing required.

It is also important to understand that GCMs provide outcomes for the global and continental scale; that is, they predict general conditions for large areas. These average conditions will not hold at smaller scales of analysis like regions and places because of the factors that influence climate at these scales (e.g., topography). It is precisely at these smaller scales, however, that data is needed in order to know how to address the effects of climate change at a local level. A critical need -- and one the science community is working on -- is to "downscale" GCMs.

Although climate change research is a sophisticated scientific endeavor, both the complexity of the earth climate system and the spatial resolution of GCMs introduce a certain level of uncertainty into the research. For example, scientists are uncertain of the complete role of oceans in the global climate system. Oceans serve as giant "sinks" or storage for carbon dioxide. But the amount of CO_2 that they store is still unknown, therefore introducing uncertainty into computer models of the climate system. In addition, the spatial resolution of GCM outputs makes it difficult to pinpoint locations where the greatest warming will occur.

Uncertainties have significant ramifications on the human responses to global change (see Unit 4). What we know and do not know with certainty will affect how and when we respond to global environmental changes. For several years, scientists and politicians have debated whether global warming was a real possibility. More recently, the debate has not been *whether* global warming will occur, but how much of a warming should we expect *when* global warming occurs.

3

Climate Change

Instructor's Guide to Activities

Goal

Students learn the basics of the earth climate system and become familiar with GCMs and their limitations. Students also become aware of the complexities of decision making in the face of an uncertain situation like the one that climate change poses.

Learning Outcomes

After completing the activities associated with this unit, students should:

- understand the interactions among the various elements of the earth climate system, including the atmosphere, oceans, and biosphere;
- be able to interpret a GCM output map;
- be able to identify, based on the GCM output, the regions and populations that face the greatest temperature increases;
- understand the concept of vulnerability to climate change;
- recognize the value and limitations of using GCMs; and
- understand the dilemma of decision making under uncertainty.

Choice of Activities[7]

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select those that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

3.1	Run-Away Warming and Cooling	-- Socratic questioning
3.2	Global Circulation Models	-- Text comprehension and GCM output interpretation
3.3	How Does Climate Change Affect Our Lives?	-- Interviewing and class discussion
3.4	"Oh, I'm Just a Bill": Decision Making in the Face of Uncertainty	-- Text reading, mock legislative hearing, oral and written testimony

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

- Background Information to Unit 3 (all students should read)
- Agarwal, A. and S. Narain. 1991. *Global warming in an unequal world: A case of environmental colonialism.* New Delhi: Centre for Science and Environment.

---

[7] For additional active learning materials and activities on climate change and greenhouse gases, see *The geography of greenhouse gases* module in this series (Liverman and Solem 1996).

- Liverman, D.M. and K. O'Brien. 1991. Global warming and climate change in Mexico. *Global Environmental Change* 1, 4 (December): 351-364.
- Trenberth, K., J. Houghton, and L.G. Meira Filho. 1996. The climate system: An overview. In IPCC. 1996a. *Climate change 1995: The science of climate change*. Cambridge: Cambridge University Press, pp. 55-64. (provided)

Activity 3.1: Run-away Warming and Cooling

Goals

This starter activity is provided as a way to capture students' attention, to engage them, and to stimulate their thinking about the climate change and the complexities of the earth's climate system.

Skills

✓ logical thinking

Material Requirements

Supporting Material 3.1 (provided)

Time Requirements

10-15 minutes

Tasks

In this activity, the instructor will use Socratic questioning to illustrate simplified positive feedback mechanisms in the earth's climate system. A suggested list of questions and expected answers are provided in *Supporting Material 3.1*. This activity should take about 10-15 minutes within a single class period depending on the instructor and the students' familiarity with the processes.

Activity 3.2: General Circulation Models

Goals

This activity demonstrates the complexity of the earth's climate system that GCMs attempt to simulate. Students interpret a GCM output map and see firsthand the coarse spatial resolution that they offer.

Skills

- ✓ analysis of schematic material
- ✓ map interpretation
- ✓ analysis of the implications of modeled quantitative estimates

Material Requirements

- *Student Worksheet 3.2* (provided)
- GCM output map (provided)
- World Atlas, depicting topographical features and elevations
- Suggested reading (provided): Trenberth et al. (1996)
- Optional reading: Liverman and O'Brien (1991)

Time Requirements

One class period (50 minutes). Activity can also be assigned as homework, if students have access to all materials outside of class.

Tasks

Part A

Students analyze a schematic diagram of the earth's climate system provided on the student worksheet and answer four questions about the diagram. The purpose of this task is to make students aware of the information that can be gathered from such a graphic and to encourage them to assess such information critically, rather than simply skipping over it while reading. (The diagram of the climate system is found in the text of the unit and on the student worksheet; many students will probably realize that they didn't take the time to 'read' the diagram in the text.) The first three questions are general questions about the climate system the answers to which students can easily derive from the diagram. The final question, asking about what is missing in the diagram, is intended to make students think about the diagram and to recognize that some activities and processes may be underrepresented.

Part B

Students use the GCM output map (provided in *Supporting Material 3.2*) to answer several questions about climate change. Students who are not familiar with maps may need some assistance understanding isolines and intervals. The purpose of the questions is for students to identify where climate change will be most severe and to realize that the greatest impacts won't necessarily always be where the greatest warming occurs. The questions also make students consider both human conditions and physical features that could make certain areas particularly vulnerable to climate changes. Students may need to consult an atlas or other references to complete the worksheet.

Activity 3.3: How Does Climate Change Affect Our Lives?

Goals

As predicted by the IPCC, one of the likely results of climate change is an increase in extreme weather events. In this activity, students learn the many ways in which extreme weather events affect our lives and make links between *global* climate change and *local* impacts.

Skills

- ✓ interviewing
- ✓ using primary data sources
- ✓ oral reporting

Material Requirements

- Blank, overhead transparencies
- Overhead markers

Time Requirements

1 class period (50minutes)

Tasks

Students will interview each other about an extreme weather event that they can recall. Divide students into pairs and ask one in each pair to serve as the "interviewer." Instruct the interviewer to ask his/her partner the following questions and to record the responses.

- Do you recall a particular extreme weather event that sticks in your mind?
- What was that event and why do you remember it?
- Did you feel vulnerable? Why or why not?
- What impact did that event have on you? On your community? On your state?

Next, have the partners switch roles and ask the same set of questions. Students should be able to identify the personal, economic, and environmental impacts of these events.

After both people have been interviewed, combine the pairs into groups of six or more students and ask them to compare the responses from the interviews. Students should be able to identify some generalizations among the different interviews. Provide each group of six with an overhead transparency and ask them to list on the overhead the generalizations that they were able to make. One student from each group should then explain the conclusions to the class.

To conclude the activity, attempt as a class to arrive at some generalizations about extreme weather events and how they affect us. Brainstorm as to how humans have contributed to these extreme events and how humans have or may act to mitigate future impacts.

Activity 3.4: "Oh, I'm Just a Bill": Decision Making in the Face of Uncertainty

Goals

Students are introduced to the difficulties in making decisions when faced with uncertainty, much like the dilemma that decision makers face when confronted by the issue of global climate change. Students prepare testimony on a piece of legislation and take part in a mock legislative hearing.

Skills

- ✓ team work
- ✓ issue analysis and position formulation
- ✓ analysis of what counts as evidence
- ✓ political-style debate
- ✓ essay writing (in form of legislative testimony)

Material Requirements

- *Student Worksheet 3.4* (provided)
- *Supporting Material 3.4* (provided)
- Suggested reading (provided): Schneider (1993)
- At least 3 or 4 friends, faculty, or graduate students to serve as the Congressional Committee on the day of the mock hearing.

Time Requirements

15-20 minutes to introduce and explain activity and an additional 50-75 minutes for students to present their work. Students will need at 1½ to 2 weeks to work on the assignment outside of class.

Tasks

Students write legislative testimony in response to a piece of proposed legislation outlined in the scenario on the student worksheet. Assign a group of students to play the role of a group of stakeholders in the proposal. A list of possible stakeholders has been provided in *Supporting Material 3.4*. Because developing the list of stakeholders can be an educational activity in itself, you may choose instead to have the students generate the list of stakeholders. In this case, *Supporting Material 3.4* should not be given to the students.

In their groups, students will first decide how their organization and constituents will be affected by global climate change and by the pending legislation. Students must assume a position on the bill and prepare written testimony to be presented to the legislative committee. Their testimony should be concise and well supported with evidence and research. You can choose to have the students simply present their testimony to the class or you can devote one class period to a mock legislative hearing.

If you choose the mock hearing, select several people to serve as Congresspersons to whom the students will present their testimony. Don't use students in the class for this role -- ask your teaching assistant, other graduate students, or some friends or faculty members to serve in these roles. The people you choose as Congresspersons should also play the role. Instruct them to act like Congresspeople. Some of them should be intimidating, loud, and visibly uninterested in the testimony. Others can appear quite the opposite. This is the reality that many people face when called to give testimony, so make this as real as possible.

Students will be evaluated on the written testimony to be turned in after the hearing and on their oral presentations to the Congresspeople. The testimony should be at least 5 pages long, but can be adjusted to fit the class situation.

3 Climate Change

Student Worksheet 3.2

Activity 3.2 General Circulation Models

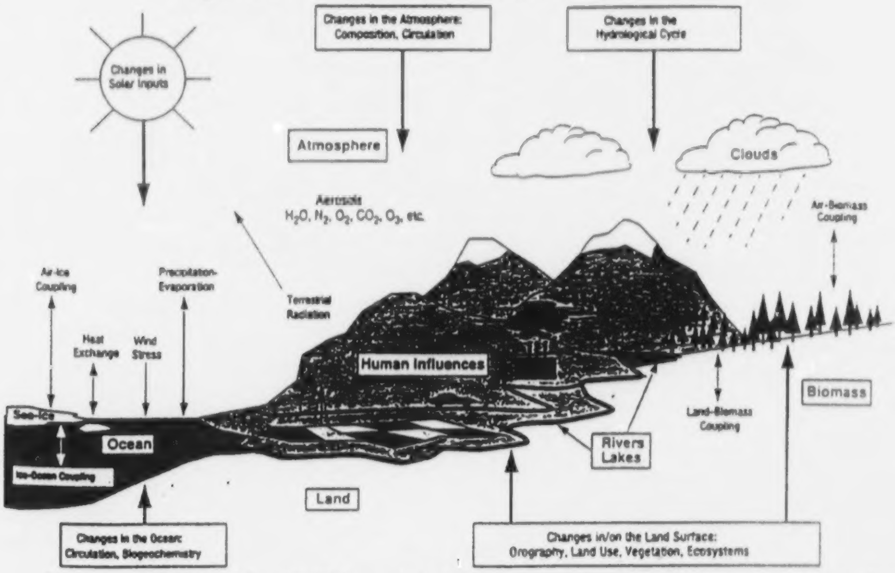
Before you begin this activity, read carefully the article by Trenberth et al. (1996) provided by your instructor.

Part A

General Circulation Models (GCMs) are computer models that scientists develop in order to simulate the way the earth and the atmosphere interact. Scientists use these models (which are usually very large and have to be run on a more powerful computer than a simple personal computer) to try and predict what would occur in the earth's climate if certain events were to occur, such as a doubling of atmospheric CO_2 concentrations.

There is, however, some debate about how accurate these models are, since modeling earth-atmosphere interactions is a highly complex process. Look carefully at the following diagram -- it is a diagrammatic representation of the kinds of processes that GCMs attempt to simulate. Note in the figure below how complex the entire system is. After examining the diagram, answer the questions that follow.

Figure 9: The Earth's Climate System


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
Aerosols
H_2O, N_2, O_2, CO_2, O_3, etc.
Air-Biomass Coupling
Air-Ice Coupling
Precipitation-Evaporation
Terrestrial Radiation
Heat Exchange
Wind Stress
Human Influences
Sea-Ice
Ocean
Ice-Ocean Coupling
Land
Rivers Lakes
Land-Biomass Coupling
Biomass
Changes in the Ocean: Circulation, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

Source: IPCC 1996. ©1996 reprinted by permission of IPCC. Andrew Dlugolecki, *Climate change 1995: Impacts, adaptations, and mitigation of climate change*.

BEST COPY AVAILABLE

Questions to Part A **Name:**

1. What are the links between the ocean and the atmosphere?

2. Where does the energy come from that drives the whole system?

3. Why is biomass important, and what major group of environmental changes that you've learned about would affect the biomass component of the diagram?

4. Is this an adequate representation of the climate system? Are any elements missing or underrepresented?

Part B

Recall the discussion of Global Circulation Models in the text of Unit 3 and in Trenberth et al. (1996). A common processes in the use of GCMs is to run the models under doubled carbon dioxide conditions, meaning that the models produce a scenario of what the earth's atmosphere would look like if the current levels of carbon dioxide in the atmosphere were doubled. Remember, carbon dioxide is a key greenhouse gas.

Look carefully at the map in *Supporting Material 3.2.* It shows the changes in surface air temperature (a good indication of global annual mean temperature) in response to doubled levels

68

of carbon dioxide in the atmosphere, predicted by a GCM designed and administered by the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey (Manabe et al. 1991). The lines traveling across the map are **isolines**, or lines that connect points of equal value. Because this map depicts temperatures, these lines are specifically called **isotherms**, or lines that connect points of equal temperature (in this case, equal temperature change). On many of the isotherms are numerical values that indicate the amount of temperature change that is expected along that line, in degrees Centigrade. A plus sign indicates an increase in temperature.

Note that the continents appear roughly drawn, almost like blocks. As mentioned in the Background Information of Unit 3, most GCMs work at a *coarse spatial resolution*, meaning that they provide only a broad indication of predicted changes; they cannot provide detailed information about where specifically the temperature changes are predicted to occur.

Activity

Using the GCM output map, answer the questions below. You may need to consult a world atlas or other references to help with your responses.

1. In global terms, where are the largest increases in temperature (above 4°C) predicted to occur, as shown by this GCM? How many people will this largest increase directly affect?

2. Can you assess the expected temperature change for a specific location such as Florida or Great Britain? Why or why not?

3. What physical or environmental features will make temperature changes in some areas more critical than others?

4. What human or social factors will make temperature change in some areas more critical than in others?

5. Will people in the areas of the greatest temperature change be able to cope with the rise in temperature ? Will they all be able to cope equally well? Why or why not?

Student Worksheet 3.4

Activity 3.2 "Oh, I'm Just a Bill": Decision Making in the Face of Uncertainty

Begin by reading the article provided by your instructor. The article should help you come to an understanding of the debate surrounding climate change and just how certain scientists can be about their predictions.

After reading the article, you will take part in a mock legislative hearing based on the scenario listed below. You and several of your classmates will be assigned by your instructor to play the role of one of the stakeholders in the hearing. Be sure to keep that perspective in mind when you read the article!

Scenario

Congressperson Watson (D-Vermont), concerned about potential impacts of global climate change, has introduced a bill to reduce CO_2 emissions in the United States by 20% by the year 2006. The bill proposes a carbon tax on electric companies that emit high amounts of carbon dioxide. The goal of the bill is to encourage the adoption of energy sources that release less carbon dioxide, such as natural gas, solar, or nuclear. The carbon taxes collected from polluters will be used to fund research on alternative energies. The House Committee considering the bill will hold a legislative hearing in which all parties with an interest in the bill can present their concerns to the Committee Members. The Committee will soon vote whether to move the bill out of committee and to the floor of Congress for debate.

Activity

As a group, your first task is to decide how the legislation, if adopted, would affect your organization and constituents. You must then decide the position that your organization will take on the proposed legislation and prepare written testimony to be presented to the Congressional Committee. You can use whatever sources you like to support your testimony. You may even choose to form coalitions with other organizations in the class that have a similar stake in the legislation's future. Remember, you will be writing and presenting to Congressional Representatives. Make your testimony clear and concise and be sure to support it well. Congresspersons won't be interested in opinion -- they will need facts in order to decide whether the bill will proceed for consideration by the entire House.

3 Climate Change

Answers to Activities

Activity 3.1: Run-away Warming and Cooling

This is a class discussion activity. The suggested questions and answers are provided in *Supporting Material 3.1*.

Activity 3.2 General Circulation Models

The answers below should be used only as a guide to evaluating students' responses to the questions on the Activity 3.2 Student Worksheet.

Part A

1. Precipitation and evaporation, heat exchange, air-ice coupling.

2. The sun.

3. Biomass is important in at least two ways. Vegetation is a sink for CO_2 and when burned releases that CO_2 into the atmosphere. Vegetation also affects the reflectivity of the earth's surface and affects the amount of solar radiation that is absorbed, reflected, or re-radiated. Terrestrial change would affect the biomass component of the diagram.

4. The diagram is fairly adequate, yet doesn't completely illustrate the role of oceans and biomass as sinks for CO_2. The diagram also simplifies human activity and the role that humans play in the climate system.

Part B

1. The largest temperature increases (above 4°C) are predicted to occur above 30° N and S latitudes. This temperature increase will directly affect the populations of North America, Europe, Northern Africa, extreme southern portions of South America, and all of Asia except India. This totals approximately 3.2 billion people.

2. It is difficult to assess the expected temperature change for Florida or Great Britain because these locations do not appear on the map because of its coarse spatial resolution.

3. Physical features that will make temperature change in some areas more critical include ice sheets or glaciers, low elevation coastal zones, and floodplains, among others.

2. It is difficult to assess the expected temperature change for Florida or Great Britain because these locations do not appear on the map because of its coarse spatial resolution.

3. Physical features that will make temperature change in some areas more critical include ice sheets or glaciers, low elevation coastal zones, and floodplains, among others.
4. Social or human factors that will make temperature change in some areas more critical include levels of economic development, institutions, population mobility, and the location of population centers, among others.

5. Some areas may be able to cope relatively well, such as the United States and Western Europe because they have the resources either to prevent serious impacts or to adapt after the fact. Areas such as northern Africa and South America may have more difficulty preventing or adapting to climate change.

Activity 3.3: How Does Climate Change Affect Our Lives?

The results of this activity will vary depending on the size of the class and the events that students recall. Allow sufficient time for the students to discuss their interviews and to make generalizations about the similarities and differences between the reports of extreme weather events.

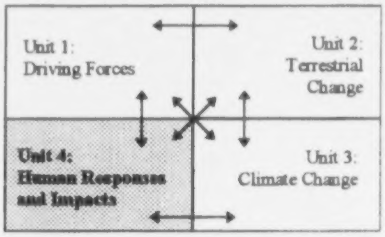
Activity 3.4 "Oh, I'm Just a Bill": Decision Making in the Face of Uncertainty

Students' written and oral testimony should be concise and well-supported with evidence. Students should not be allowed simply to state their group's opinions -- they must support that opinion. Good testimony requires that students do additional research in order to formulate their group's position. The oral presentations should be professional and should clearly articulate the concerns of the group. The instructor should structure the hearing such that students are able to adopt their roles and enjoy themselves.

4

Human Impacts and Responses

Background Information



In this unit, we come full circle in our study of global environmental change by looking at human impacts and responses. How will we be affected by global changes and how will we respond? The answer to this question has profound implications for humankind and has significant socioeconomic and political meaning.

Human impacts and responses are a cyclical process. How individuals and society respond to global change, climatic change or otherwise, restructures the very actions that triggered the human component of that change in the first place. For example, if stock farmers in the United States were forced by diminished vegetation cover (because of increased frequency of droughts, for instance) to send their stock onto steeper land to graze, the vegetation cover would decrease at an increasing rate, since the steeper slopes are more prone to erosion when vegetation is regularly removed. Land deterioration on this scale affects the productivity of the agricultural market, which is reflected in food prices and quality. Farmers would be economically as well as environmentally stressed and may be forced to make progressively more damaging environmental decisions.

In the following section, we consider the ways in which we may respond to global environmental changes with a specific focus on global climate change.

Human Responses to Environmental Change

The US National Research Council (NRC) has developed an analytical framework for understanding the possible human responses to global environmental changes (Stern, Young, and Druckman 1992). Their framework includes:

- **Responses to experienced versus anticipated change**: People and social institutions respond to environmental change both as it is experienced (after the fact) or as it is anticipated. In the past, the former response tended to be more prevalent; however, with increasing scientific knowledge, anticipatory responses have become possible.

- **Deliberate responses versus actions taken with incidental effects**: Some human actions can be taken as a deliberate response to environmental change. For example, the building of dikes in coastal areas may protect some populations from rising sea levels. On the other hand,

BEST COPY AVAILABLE

some human actions may have incidental effects on environmental change. A large tax increase on gasoline, enacted for a reason unrelated to global change, may have the incidental effect of reducing CO_2 emissions and slowing the pace of global warming.

- **Coordinated versus uncoordinated responses**: Some human responses may be coordinated actions taken by governments or other organizations. Other actions may be uncoordinated, such as those undertaken by individuals.

The NRC notes that interventions may occur at any time in the cycle of interaction between human and environmental systems. Humans may choose to mitigate, adapt, or adjust in response to environmental changes.

Mitigation describes an action that *prevents, limits, delays, or slows* the rate of undesired impacts by acting on either the environmental system, the human **proximate forces**, or the human systems that drive environmental change. Using climate change as an example, humans could intervene on the environmental system by blocking solar radiation with orbiting particles that reflect solar radiation. Humans could also intervene on the proximate forces by regulating automobile use to control CO_2 emissions. Lastly, humans could intervene in human systems by investing in research on renewable energy sources.

Adaptation is another action that humans may undertake in response to environmental change. Adaptation includes activities such as *blocking* or *adjusting* to environmental changes. *Blocking* is an action that prevents the change from having an impact on a valued environmental system. Unlike mitigation, blocking does not prevent the undesired event from occurring; rather it prevents it from affecting something that humans value. For example, farmers may introduce drought resistant crops to block the effects of climate change on the agricultural system. *Adjusting* neither prevents a change from occurring, nor does it prevent it from affecting a valued environmental system. Rather, an adjustment is a response to the occurrence of the change. For example, humans may adjust to sea level rise by migrating away from low-lying coastal areas.

A variation of adaptation is **anticipatory adaptation** in which actions are undertaken to improve the ability of social systems to withstand environmental change before it occurs. For example, farmers may choose to diversify their agricultural systems by growing polycultures which may be more robust to the effects of environmental changes. When climate change occurs, the risk of total crop failure and possible famine would be reduced as a result of the anticipatory action taken by the farmer.

Now that we've looked at a general framework of responses to global environmental changes, let's look at how the world has actually responded to the threat of global climate change.

International Responses to Climate Change

Attempts to mitigate or intercede to reduce potential climate change are difficult because they involve different perspectives and values and they require compromise. The policies that result have immediate economic, social, and political consequences. For example, consider how difficult it would be to institute the automobile emissions-reducing plan of Mexico City whereby each car can not be used one day of the week, in a particular community. Who would have objections and what might these objections be?

The United Nations General Assembly established the Intergovernmental Panel of Climate Change (IPCC) to advise the world on the potential for climate change, its physical consequences, and the likely effects of various responses. One of the central questions is the cost effectiveness of strategies aimed at reducing greenhouse gases to stave off climate change versus strategies that assist humankind to adjust to the new conditions (Nordhaus 1992; Rosenberg and Crosson 1991). The answers, of course, are too full of uncertainties to command authority. What is clear from most assessments is that there will be winners and losers (Rosenzweig and Hillel 1993); some areas of the world will benefit from climate change and others will suffer negative impacts. Given the regional differences in environmental changes that are projected and the regional differences in the ability to adjust (e.g., developed vs. less developed parts of the world), the regions of the world already suffering from poverty and other problems (in other words, those areas that are most vulnerable) seem the most likely to bear the brunt of climate change impacts.

The IPCC notes that human interventions may occur at many different points in the four-box illustration shown at the beginning of each unit of this module. The IPCC also emphasizes the pivotal role of conflict in the assessment and selection of intervention strategies -- not only because intervention strategies have variable consequences for variable interests (e.g., current industrial activity, tax policies, or developing world farmers) but because intervention or the lack of it involves human values in different ways. These themes are illustrated in the example below.

At the United Nations Conference on Environment and Development (UNCED) meeting in Rio de Janeiro in 1992 known as the Earth Summit, 167 nations signed the Framework Convention on Climate Change (FCCC) with the aim of reducing greenhouse gas emissions and therefore the risk of global warming. Each nation was required to prepare a climate action plan identifying the major sources of greenhouse gas emissions within their country and ways of reducing them.

In 1995, the Berlin Climate Summit provided the first chance since the Earth Summit for governments who signed and ratified the FCCC to commit themselves to further reduction of greenhouse gases. Only countries who have ratified the Convention now have the right to participate in the on-going, formal decision-making process. Debate continues about whether the reduction of emissions committed to by the ratifying countries will be sufficient to stabilize CO_2 levels in the atmosphere.

Both the Rio and Berlin Summits produced interesting sets of alliances and agendas among countries. At least three major groupings emerged: the developing South, the industrialized North, and the "energy" export countries. The North-South distinction refers to the prevalence of developed countries in the northern hemisphere (primarily north of 30° latitude), and developing countries in the southern hemisphere. Table 2 lists the developing and developed regions based on a "Human Development Index" (HDI) created by the United Nations. The HDI combines three indicators of economic development: per capita purchasing power, life expectancy at birth, and literacy rate. The minimum for each of the indicators was set at the lowest level observed in any country. The maximum levels were 100% for literacy, the maximum observed life expectancy in any country, and the official poverty level in nine relatively developed countries (Rubenstein 1992).

Table 6: Developed and Developing Regions of the World

Developing Regions	Human Development Index	Developed Regions	Human Development Index
Latin America	.80	Japan	.99
Middle East	.70	Western Europe	.98
East Asia	.70	South Pacific	.97
Southeast Asia	.60	Anglo-America	.96
South Asia	.40	Eastern Europe	.92
Sub-Saharan Africa	.30	South Africa	.73

Source: Data extracted from Rubenstein. 1992. *The cultural landscape: An introduction to human geography*. New York, NY: MacMillan.

The perspective of the developing South, which has the least ability fiscally to adapt, is that climate change is a problem that has been produced by the industrialized North. High levels of production and consumption in developed countries have contributed the highest amounts of greenhouse gases to the atmosphere, and therefore those countries should take the first steps on reducing emissions. The countries of the North, however, are not interested in efforts to reduce emissions that will affect their economies, and their populations are not keen on reducing consumption habits.

The countries of the industrialized North recognize their role to date in greenhouse gas emissions and have the greatest ability not only to reduce these emissions but to adapt to climate change. Reducing greenhouse gases, however, has enormous consequences for the economies of the North. No country wants to agree to policies that will negatively affect their own industrial base. For this reason, the North is more likely to point to population increases in the South as the larger problem because the exponential population growth there makes the development transition more difficult (although this claim is disputed by some).

Energy exporting countries have not favored the convention to reduce greenhouse gases because to do so would, they believe, drive down the use of fossil fuel energy and negatively affect their own economies.

The general lessons here are repeated elsewhere in regard to global change either in individual or collective responses:

- we seek to protect our own behaviors not change them, especially when change is perceived to have negative impacts on our lifestyles;
- and we seek to find solutions in the behavior of others.

Negotiated solutions are, therefore, extremely difficult to achieve. It is far easier to point to the need for more research than it is to find solutions. This suggests that a business-as-usual outcome is highly likely. If this is the case and the global climate models are correct, then we can expect that adaptation, rather than prevention, will be the global response by default. In this scenario, the more-developed North will be advantaged over the less-developed South.

Conclusion

Throughout this module we have explored global environmental changes and the ways that humans have contributed to these changes. In particular, we've seen how human activity has altered terrestrial ecosystems and affected the global climate. We've also seen how humans have responded to the changes that they have produced.

Consider for a moment that the changes in climate predicted by the IPCC will take place during your lifetime. By the time your children are in college, the global annual mean temperature is predicted to have increased by 2°C and sea levels are predicted to have risen by 50 cm. What will this mean for your life and your children's lives? Will you be one of the "winners" or one of the "losers"? If we are unable to prevent further global environmental changes and respond effectively to those that are already underway, won't we all be the "losers"?

4

Human Impacts and Responses

Instructor's Guide to Activities

Goal

Students learn the range of possible human responses to global environmental change.

Learning Outcomes

After completing the exercises associated with this set of activities, students should:

- know the range of potential human responses to environmental change;
- recognize the complexities in creating an international response to global change;
- have a basic understanding of the distinctions between North-South and developed-developing countries' positions and their importance in responding to environmental change;
- recognize the value of "visions" in creating a sustainable future; and
- understand how decisions made today in response to global change will have impacts on future generations.

Choice of Activities

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select those that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

4.1	Conflicting Priorities: The Environment-Development Debate	-- Critical text reading, question formulation, and class discussion
4.2	Time Capsule	-- Letter writing to relative in 2100 defending response to climate change
4.3	Future Worlds, Visions, and Film	-- Analysis of representations of future world(s) in film
4.4	Visions of Our Common Future	-- Written or artistic expression of a future sustainable world

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

- Background Information to Unit 4 (all students should read)
- Haas, P., M. Levy, and E. Parson. 1992. Appraising the Earth Summit. *Environment* 34 (8): 6-11, 26-33.

- IPCC. 1996b. *Climate change 1995: Impacts, adaptations, and mitigation of climate change*. R. Watson, M. Zinyowera, R. Moss, and D. Dokken, eds. New York: Cambridge University Press, selected chapters.
- Liverman, D. 1990. Vulnerability to global environmental change. In R. Kasperson, K. Dow, D. Golding, and J. Kasperson, eds. *Understanding global environmental change: The contributions of risk analysis and management*. Worcester, MA: Clark University.
- Pallemaerts, M. 1994. International environmental law from Stockholm to Rio: Back to the future? In P. Sands, ed. *Greening international law*. New York: The New Press, Chapter 1.
- Schneider, S. 1993. Degrees of certainty. *National Geographic Research and Exploration* 9 (2): 173-190. (provided)
- Schnoor, J. 1993. The Rio Earth Summit: What does it mean? *Environmental Science and Technology* 27 (1): 18-22.
- Stern, P; O. Young, and D. Druckman, eds. 1992. *Global environmental change: Understanding the human dimensions*. Washington: National Academy Press, *Chapter 4: Human Consequences and Responses*.
- United Nations Environment Program (UNEP). 1997. Policy responses and directions. In *Global environment outlook*. New York, NY: Oxford University Press, pp. 129-142.

Activity 4.1: Conflicting Priorities: The Environment-Development Debate

Goals

Students become familiar with international responses to global environmental change.

Skills

- ✓ critical thinking
- ✓ key-point and issue identification
- ✓ listening skills
- ✓ speaking

Material Requirements

- *Student Worksheet 4.1* (provided)
- Suggested readings: Haas, Levy, and Parson (1992), Schnoor (1993), and Pallemaerts (1994)

Time Requirements

1 class period (50 minutes), plus additional time (4-5 days) for students to prepare before the in-class activity.

Tasks

As homework, students read three articles regarding UN initiatives to protect the environment, including the 1972 Stockholm initiative, the 1987 Brundtland Report, and the 1992 Rio Earth Summit. After reading the articles, students prepare written responses to the questions on the student worksheet and bring them to class on the assigned day. Students must also write 2 or 3 additional questions of their own and bring them for the class discussion. Students must have the assignment completed and must give their written responses to the instructor as the "ticket" to participate in the day's discussion. Students without written responses will not be allowed to participate. Participation in the day's discussion should be an exercise in which students earn credit for participation.

In class, ask students to form a circle. In a small classroom, have students arrange desks in a circular pattern. Select one student to begin. The student will have a limited time period to present a few thoughts that arose during her/his readings of the homework and then arrive at a question to pose to the next student. That student then will have the same amount of time to consider the question, think aloud, and lead into another question. This continues around the class until all have participated. The process allows students to articulate what they do or do not understand in a spontaneous way and allows the class to work through the readings together. Students shouldn't use their scripted questions because their question should flow from the one that precedes them. The process through which the discussion evolves is just as interesting as the questions considered. Students should not be given more than 4-5 minutes to speak. This will have to be adjusted based on the size of the class. One important rule is that no student is allowed to speak until it is his/her turn. This prevents interruption and encourages active listening.

Activity 4.2: Time Capsule

Goals
Students consider the possible responses to an environmental change like global warming, select a response, and defend it to a relative alive in the year 2100.

Skills
- ✓ essay writing
- ✓ definition of values
- ✓ support and justification of personal decision

Material Requirements
- *Student Worksheet 4.2* (provided)

Time Requirements
2-3 days outside of class

Tasks
Each student writes a two-page letter to a descendant to be placed into a time capsule and opened in the year 2100. Students must choose an appropriate response to global warming (i.e., "we need more research, so we should wait" or "we should immediately reduce CO_2 emissions worldwide") and defend that decision to their relatives, who in 2100, will be experiencing the effects of our decisions today. Students should make links back to the "mitigate, adjust, block, adapt or anticipate" options presented in the readings. You may choose to have students share their letters with the class and to discuss the various perspectives in the class.

Activity 4.3 Future Worlds, Visions, and Film

Goals

Students become aware of how images of the future in film, books, news reports, and other media affect their own visions of the future.

Skills

- ✓ film comprehension
- ✓ interpretation of information
- ✓ critical discussion of movie

Material Requirements

- *Student Worksheet 4.3* (provided)
- A film such as *Mad Max Beyond Thunderdome*, *Waterworld*, *Dune*, *2010*, *Soylent Green*, or others of this genre.

Time Requirements

One class period (50 minutes)

Tasks

Choose a film that depicts the world sometime in the future and select a 10-15 minute clip from the film that illustrates this future well. If time permits, you can show multiple clips from different movies or even show one entire film. Students then break into groups of 2 or 3 and answer and discuss the questions on the Student Worksheet. All of the films suggested above should be available at a local movie rental store or through interlibrary loan.

Activity 4.4 Visions of Our Common Future

Goals

Students envision the world they would like to see for their children or grandchildren and present their vision in a creative way.

Skills

- ✓ creative writing
- ✓ futures thinking
- ✓ envisioning

Material Requirements

- *Student Worksheet 4.4* (provided)

Time Requirements

5-7 days outside of class. If instructor chooses t
the activity will require at least one additional cl

Tasks

In this activity, students are "allowed the luxury
essay in which they describe the world they wou
allow students to be as creative as they want to
drawings, paintings, photos, or other creative m
The instructor may choose to have students pres
visions to initiate a class discussion about the ac
worlds they have envisioned.

or chooses to have students present their visions to the class,
dditional class period (50 minutes).

the luxury of dreaming." Students will prepare a written
d they would like to see in the year 2050. Instructors should
ey want to be on this exercise. Students may opt to use
creative media to as an alternative to the written assignment.
udents present their visions to the class and/or use the
bout the actions that need to be taken now to create the

4 Human Impacts and Responses

Student Worksheet 4.1

Activity 4.1 Conflicting Priorities: The Environment-Development Debate

Preparation before class
Read the three articles provided by your instructor. Each one describes United Nations initiatives to protect the environment, including the:

- 1972 initiative in Stockholm
- 1987 Brundtland Report
- 1992 Rio Earth Summit

Try not to get caught up in the fine details of the readings, but make sure that you have the basic ideas. As you read, consider the questions listed below. Prepare a one-paragraph response to each question and bring it to class with you on the day of discussion. In addition, come up with 2 or 3 questions of your own (you don't have to answer these!) and bring them to class too. These written responses will serve as your "ticket" to participate in the day's discussion. Participation in the discussion will be for credit.

Questions to Consider
There is a 20-year time span between the Stockholm initiative and the Rio Summit, and yet many of the issues in the two reports are the same.

1. What has changed in the UN initiatives during the 20-year period?
2. What are the barriers that have slowed or prevented effective response?
3. Do you feel that the UN's attempt to make priorities of environment *and* economic development have been successful?
4. Can *environment* and *development* be treated as separate issues?

Student Worksheet 4.2

Activity 4.2 Time Capsule

How do you think the US or the world should respond to the threat of global climate change? Write a letter to be placed into a time capsule and opened in the year 2100 by one of your descendants. In this letter, defend the response chosen by earth's inhabitants in dealing with global climate change. To begin, select the response *you* think is most appropriate (i.e., adapt, adjust, mitigate, wait for more research, or others) and defend it to those people living during the time for which most of the impacts from current activities are predicted to occur. You may need to refer to the suggested readings, your class notes, the background information of this module, or other references. Your letter should be written as if you were writing to a relative and should be no more than two pages in length.

Student Worksheet 4.3 Name

Activity 4.3 Future Worlds, Visions, and Film

Many of us have a vision of what the world will be like in the future. These visions may be shaped by the books we read, the films we see, news reports we hear, or a variety of other factors. Films like *Mad Max Beyond Thunderdome*, *Waterworld*, *Dune*, *2010*, or *Soylent Green*, among others, all present visions of our world in the future and quite often, these visions are less than positive.

In this activity, you will consider your vision of the world's environmental future and the ways in which that vision has been created. Your instructor will show you a short clip from a recent film or video. After you watch the clip, you will break up into groups of 2 or 3 and discuss the questions below.

---

1. Do you have a vision of what the world will be like, environmentally, in the year 2050? If so, describe it. Is it a picture? Is it in words? Is it a general impression or a feeling of foreboding?

2. Where does your vision come from (newspapers, scientific journals, books, films)? How does your own general optimism or pessimism (or beliefs) filter your vision of the future? In other words, if someone were to tell you that the future will be excellent, would you believe them?

3. Are you able to "envision" something else? Can you envision a positive future, if you currently have a negative perspective? Why might a positive vision be important to us as we confront global environmental changes?

Student Worksheet 4.4

Activity 4.4 Visions of Our Common Future

An important part of responding to an issue such as environmental change is having a *vision* by which our personal lives, and by extension, our societal and governmental policies should be guided. In their book *Choosing Our Future: Visions of A Sustainable World*, Nagpal and Foltz (1995) ask more than 50 people from 34 countries to provide their visions of the world they would like to see for their children in the year 2050. The authors write, "to alter our present course and assure a more sustainable future, we must allow ourselves the luxury of dreaming. Visioning is a powerful tool for escaping the confines of ideas and paradigms that lock us into many unsustainable patterns of behavior" (Nagpal and Foltz 1995, p.2).

In this activity, you will create a vision of the world *you* would like to see for yourself or for your children in the year 2050. Do not predict what the world will be, but rather *imagine* a positive future. Write your thoughts as they come to you. Try to avoid academic-style writing, and rather focus on your own personal thoughts, emotions, feelings--your vision. Convey what is most important to you in your vision of the future.

As an alternative to writing, you can graphically depict your vision of the future. You can draw it, paint it, or choose whatever medium you would like to illustrate the world you want to see.

Present your vision to the class on the assigned day. This activity will be for credit, but have fun, and be as creative as you like. Remember, "allow yourself the luxury of dreaming."

4 Human Impacts and Responses

Answers to Activities

Activity 4.1 Conflicting Priorities: The Environment-Development Debate

Use the following general information as a guide for evaluating the responses to the questions on the student worksheet.

1. The students should discuss the claim that UN initiatives have taken a more development-oriented perspective and have begun to make explicit the links between economic development and environmental degradation. For example, initiatives have begun using the words "sustainable development," and Agenda 21 at the Rio Summit created a new UN body known as the Sustainable Development Commission.

2. There are many possible responses to this question. One that is clear in the readings is the lack of funding that industrialized nations are willing to provide for many of the initiatives. For example, it is estimated that implementing Agenda 21 would require $600 billion per year, with $125 billion coming from industrialized countries. At the time the article (Haas et al. 1992) was written, funding had only reached $60 billion annually. Another barrier has been the successful attempts at weakening the initiatives. For example, the language of the Climate Convention was watered down (at the US's insistence) to create unenforceable broad goals rather than enforceable target emissions levels (Schnoor 1993).

3. This is an opinion question, and responses will vary. Students should support their answers with information from the articles, regardless of their choice.

4. Again, this question is a matter of opinion and responses will vary. The articles, however, do make a clear case for not considering environment and development as separate issues.

Activity 4.2 Time Capsule

This is a creative writing exercise in which student responses will vary. Use the criteria below as a guide for evaluating their work. See *Notes on Active Pedagogy* for additional suggestions on evaluating students' written work.

- Did the student select a feasible response to climate change?

- Was the selected response from the list provided in the *Background Information*, or some form thereof?
- Did the student persuasively defend that choice? Did the student provide reasons for *not* selecting other options?
- Did the student provide enough evidence to convince the reader of the logic of his/her choice?
- Did the student follow the letter format, yet write a clear, creative, and convincing essay?

Activity 4.3 Future Worlds, Visions, and Film

There are no right or wrong answers to the questions on the Student Worksheet. After the film clip when students get into their groups to discuss the questions, walk around the room and make sure that the conversations are on track and that all group members are participating. The first question makes students aware of how they themselves and how others imagine the future. The second question is intended to make students aware of how their own personal values and beliefs can affect this vision. The third question is intended to encourage students to envision a positive future and to consider why having a positive vision may be necessary to help confront the challenges of global environmental change.

Activity 4.4 Visions of Our Common Future

It is important that students be allowed the freedom to be creative and imaginative with this project. As the exercise suggests, students should have the luxury of dreaming, and therefore, should feel free to express their vision in whatever form they choose. For these reasons, the instructor may choose to evaluate this exercise on a credit--no credit basis. Worrying about whether they will receive a letter grade may inhibit some students. If letter grades are important or necessary for the instructor, it may be wise to skip this activity.

Glossary

Note: Terms that appear in **bold** in the right-hand column below are defined elsewhere in this glossary.

adaptation	a potential human response to environmental change, involving either an adjustment to the change, or a blocking of the impact on a valued environmental system.
anticipatory adaptation	an adaptive response to environmental change that aims to improve the ability of social systems to withstand such change.
biodiversity	the variety and variability of life forms on earth, both wild and domesticated; derived from the words *biological diversity*.
biosphere	the parts of the earth's lithosphere, atmosphere, pedosphere, cryosphere, and hydrosphere in which all living organisms exist and interact; the zonal space extending from the immediate subsurface of the earth to the upper atmosphere.
climate	the accumulation of daily and seasonal **weather** events over a long period of time.
climate change	a change of **climate** that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods (from the United Nations Convention on Climate Change).
driving forces	societal forces that bring about global environmental change, including population, economy, technology, ideology, and social organizations.
ecosystem	self-regulating natural community of plants and animals interacting with one another and with their non-living environment.
enhanced greenhouse effect	the increase in the strength of the natural **greenhouse effect**, resulting from human activities that release additional quantities of **greenhouse gases** into the atmosphere.
evapotranspiration	the combined water loss to the atmosphere from (1) ground and water surfaces through evaporation and (2) plants through transpiration.

Geographic Information Systems (GIS)	computer-based systems that are designed to accept, organize, analyze, and display diverse types of spatial information.
greenhouse effect	the trapping of heat in the earth's atmosphere. Incoming short-wave solar radiation penetrates the atmosphere, but long-wave outgoing radiation is absorbed by the **greenhouse gases** in the atmosphere and is re-radiated to the earth, causing a rise in atmospheric temperature.
greenhouse gases	gases present in the earth's atmosphere, including water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), and chlorofluorocarbons (CFCs), that cause the **greenhouse effect**.
global annual mean temperature	the average surface temperature per year for the entire planet.
global circulation models (GCMs)	complex computer models of the earth's climate system designed to help scientists learn about the interactions among the atmosphere, the oceans, the lithosphere, and the **biosphere**.
gross national product (GNP)	total market value of all goods and services produced per year in a country.
IPAT	equation ($I = P \times A \times T$) developed by Paul Ehrlich and John Holdren in 1972 to describe the variables that interact to produce environmental change; impact (I) or magnitude of environmental change is a function of the interaction among population size (P), affluence (A), and technology (T).
isoline	a line that connects points of equal value on a map.
isotherm	a line that connects points of equal temperature on a map
land cover	the physical state of the land, including the quantity and type of surface vegetation, water, and earth materials.
land use	the human employment of land; includes settlements, cultivation, pasture, rangeland, and recreation, among others.
land-cover change	a change from one class of **land cover** to another (*conversion*), such as from grassland to cropland, or a change of condition within a **land cover** category (*modification*), such as the thinning of a forest.
land-use change	shift to a different **land use** or an intensification of an existing one.

mitigation	any actions that prevent, limit, delay, or slow the rate of undesired impacts by acting on either the environmental system, the human **proximate forces**, or the human systems that drive environmental change.
non-proximate forces of change	forces of change that underlie, at various levels, the **proximate forces of change**.
positive feedback	flow of energy or information into a system that causes the system to change continuously in the same direction; as a result, the system can go out of control.
proximate forces of change	human actions that directly alter the physical environment.
remote sensing	the measurement or acquisition of information of some property of an object of phenomenon, by a recording device that is not in physical contact with the object under study (i.e., the use of satellites to gather information about the earth's land cover).
terrestrial ecosystem	a land-based **ecosystem**, such as forests, deserts, grasslands, or croplands, among others.
terrestrial change	a type of environmental change resulting in the alteration of **terrestrial ecosystems**; includes **land-use and land-cover change**.
scatterplot	graph used to display the relationship between two quantitative variables.
vulnerability	in terms of environmental change, the potential (susceptibility) for loss or the capacity to suffer harm from such change(s).
weather	the conditions of the atmosphere at any particular time and location.

References to All Units

Agarwal, A. and S. Narain. 1991. *Global warming in an unequal world: A case of environmental colonialism*. New Delhi: Centre for Science and Environment.

Brown, Dwight. 1996. *Living in the biosphere: Production, pattern, population, and diversity*. Washington, DC: Association of American Geographers.

Gabler, R., R. Sager, and D. Wise. 1991. *Essentials of physical geography*. Philadelphia, PA: Saunders College Publishing.

Gleick, P. 1993. *Water in crisis: A guide to the world's freshwater resources*. New York, NY: Oxford University Press.

Goldsmith, E., N. Hildyard, P. McCully, and P. Bunyard. 1990. *Imperiled planet: Restoring our endangered ecosystems*. Cambridge: MIT Press.

Haas, P., M. Levy, and E. Parson. 1992. Appraising the Earth Summit. *Environment* 34 (8): 6-11, 26-33.

Intergovernmental Panel on Climate Change (IPCC). 1996a. *Climate Change 1995: The Science of Climate Change*. J.T. Houghton, L.G.M. Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds. Cambridge: University of Cambridge Press.

________. 1996b. *Climate change 1995: Impacts, adaptations, and mitigation of climate change*. R. Watson, M. Zinyowera, R. Moss, and D. Dokken, eds. New York, NY: Cambridge University Press.

________. 1990. *Climate Change: The IPCC scientific assessment*. J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds. Cambridge University Press, Cambridge.

Jacques, A.P. 1992. *Environmental protection series: Canada's greenhouse gas emissions: estimates for 1990*. Report EPS 5/AP/4, Environment Canada.

Kasperson, J.X., R. E. Kasperson, and B.L. Turner II, eds. 1995. *Regions at risk: Comparisons of threatened environments*. United Nations University.

Kuby, Michael. 1996. *Population growth, energy use, and pollution: Understanding the driving forces of global change*. Washington, DC: Association of American Geographers.

Liverman, D.M. and K. O'Brien. 1991. Global warming and climate change in Mexico. *Global Environmental Change* 1, 4 (December): 351-364.

Manabe, S., R. J. Stouffer, M. J. Spelman, and K. Bryan. 1991. Transient responses of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2: Part I: Annual mean response. *Journal of Climate* 4 (August): 785-818.

McKendry, J.E., J.R. Eastman, K. St. Martin, and M.A. Fulk. 1995. *Applications in forestry. Explorations in geographic information systems technology: Volume 2.* Geneva: United Nations Institute for Training and Research.

Meyer, W.B. and B.L. Turner II, eds. 1994. *Changes in land use and land cover: A global perspective.* Cambridge: University of Cambridge Press.

________. 1992. Human population growth and global land-use/cover change. *Annual Review of Ecology and Systematics* 23: 39-61.

Miller, G. Tyler. 1990. *Living in the environment.* Belmont: Wadsworth Publishing Company.

Moser, Susanne. 1996. *Human driving forces and their impacts on land use/land cover.* Washington, DC: Association of American Geographers.

Nagpal, T. and C. Foltz, eds. 1995. *Choosing our future: Visions of a sustainable world.* Washington, DC: World Resources Institute.

Nordhaus, W.D. 1992. An optimal transition path for controlling greenhouse gases. *Science* 258: 1315-1319.

Pallemaerts, M. 1994. International environmental law from Stockholm to Rio: Back to the future? In P. Sands, ed. *Greening international law.* New York, NY: The New Press, Chapter 1.

Pierce, J. 1990. *The food resource.* Essex: Longman.

Piexoto, J.P. and A.H. Oort. 1992. *Physics of climate.* New York, NY: American Institute of Physics.

Richards, P. 1990. Land transformation. In Turner et al., eds. *The earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years.* Amsterdam: Cambridge University Press.

Rosenberg, N.J. and P.R. Crosson. 1991. The MINK project: Processes for identifying regional influences of and responses to increasing atmospheric CO2 and climate change. *Environmental Conservation* 18: 313-322.

Rosenzweig, C. and D. Hillel. 1993. Agriculture in a greenhouse world. *National Geographic Research & Exploration,* Spring, pp. 208-221.

Rubenstein, J.M. 1992. *The cultural landscape: An introduction to human geography*. New York, NY: Macmillan.

Schneider, S.H. 1993. Degrees of certainty. *National Geographic Research & Exploration* 9, 2: 173-190.

Schnoor, J. The Rio Earth Summit: What does it mean? *Environmental Science and Technology* 27 (1): 18-22.

Stern, P.C., O.R. Young, and D. Druckman, eds. 1992. *Global environmental change: Understanding the human dimensions*. Washington, DC: National Academy Press.

Trenberth, K.E., J.T. Houghton, and L.G.M. Filho. 1996. The climate system: An overview. In IPCC. *Climate Change 1995: The Science of Climate Change*. Cambridge: University of Cambridge Press, pp. 55-64.

Turner, B.L. II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds. 1990. *The earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years*. Amsterdam: Cambridge University Press.

United Nations Environment Program (UNEP). 1997. Policy responses and directions. In *Global environment outlook*. New York, NY: Oxford University Press, pp. 129-142.

United States Bureau of the Census. 1995. *Statistical abstracts of the United States*. Washington, DC: Government Printing Office.

________. 1977. *Statistical abstracts of the United States*. Washington, DC: Government Printing Office.

Warrick, R. and G. Farmer. 1990. The greenhouse effect, climatic change and rising sea level: Implications for development. *Transactions of the Institute of British Geographers* 15: 5-20.

World Resources Institute (WRI). 1996. *World Resources 1996-97*. New York, NY: Oxford University Press.

Supporting Materials

The materials in this section support the background information and the student activities. Each *Supporting Material* is numbered according to the section or activity in which it may be used. For example, *Supporting Material 1.1* accompanies *Activity 1.1*.

Registered Automobiles by State
1976 and 1993

(In millions)

State	1976	1993
Alabama	1.96	2.14
Alaska	.26	.31
Arizona	1.08	2.07
Arkansas	.89	.99
California	11.31	17.30
Colorado	1.49	2.25
Connecticut	1.85	2.46
Delaware	.30	.43
D.C.	.25	.25
Florida	4.65	8.07
Georgia	2.54	3.96
Hawaii	.41	.66
Idaho	.43	.64
Illinois	5.48	6.65
Indiana	2.60	3.41
Iowa	1.57	1.95
Kansas	1.26	1.26
Kentucky	1.74	1.71
Louisiana	1.73	2.01
Maine	.52	.79
Maryland	2.15	2.96
Massachusetts	2.84	3.33
Michigan	4.75	5.73
Minnesota	1.98	2.91
Mississippi	1.02	1.53
Missouri	2.22	2.86
Montana	.38	.56
Nebraska	.85	.94
Nevada	.36	.63
New Hampshire	.42	.74
New Jersey	3.88	5.18
New Mexico	.58	.86
New York	6.87	8.75
North Carolina	2.96	3.84
North Dakota	.34	.40
Ohio	6.55	7.48
Oklahoma	1.46	1.76
Oregon	1.36	2.00
Pennsylvania	6.85	6.60
Rhode Island	.51	.59
South Carolina	1.48	2.00
South Dakota	.35	.49
Tennessee	2.17	3.99
Texas	6.36	8.88
Utah	.61	.84
Vermont	.24	.36
Virginia	2.83	4.13
Washington	1.96	3.12
West Virginia	.76	.83
Wisconsin	2.20	2.46
Wyoming	.21	.28

Source: US Bureau of the Census 1976 and 1995.
Statistical abstracts of the United States. Washington, D.C.

BEST COPY AVAILABLE

Vegetation and Precipitation Data

Site #	Precipitation (inches per year)	Vegetation Cover (%)
1	5	15
2	34	42
3	130	79
4	3	10
5	44	32
6	118	87
7	2	9
8	36	42
9	29	24
10	90	71
11	37	42
12	94	73
13	1	9
14	40	52
15	1	9
16	200	89
17	91	75
18	40	32
19	3	11
20	103	87
21	38	49
22	11	21
23	91	73
24	37	28
25	61	65
26	41	48
27	35	32
28	64	62
29	203	91
30	33	31

Rainforest Information Sheet

Rates of Rainforest Loss

Rainforests cover less than 2% of the Earth's surface, yet they are home to some 50 to 70% of all life forms on our planet. The rainforests are quite simply, the richest, oldest, most productive and most complex ecosystems on Earth. As biologist Norman Myers notes, *"rainforests are the finest celebration of nature ever known on the planet."* And never before has nature's greatest orchestration been so threatened.

Global rates of Destruction

- 2.47 acres (1 hectare) per second: equivalent to two US football fields
- 150 acres (60 hectares) per minute
- 214,000 acres (86,000 hectares) per day: an area larger than New York City
- 78 million acres (31 million hectares) per year: an area larger than Poland

In Brazil

- 5.4 million acres per year (estimate averaged for period 1979-1990)
- 6-9 million indigenous people inhabited the Brazilian rainforest in 1500; in 1992, less than 200,000 remain

Species Extinction

- Distinguished scientists estimate an average of 137 species of life forms are driven into extinction every day, or 50,000 each year.

Projected Economic value of One Hectare in the Peruvian Amazon

- $6,820 per year if intact forest is sustainably harvested for fruits, latex, or timber
- $1,000 if clear-cut for commercial timber (not sustainably harvested), or $148 if used as cattle pasture.

While you were reading the above statistics, approximately 150 acres of rainforest were destroyed. Within the next hour approximately six species will become extinct. While extinction is a natural process, the alarming rate of extinction today, comparable only to the extinction of the dinosaurs, is specifically human-induced and unprecedented .

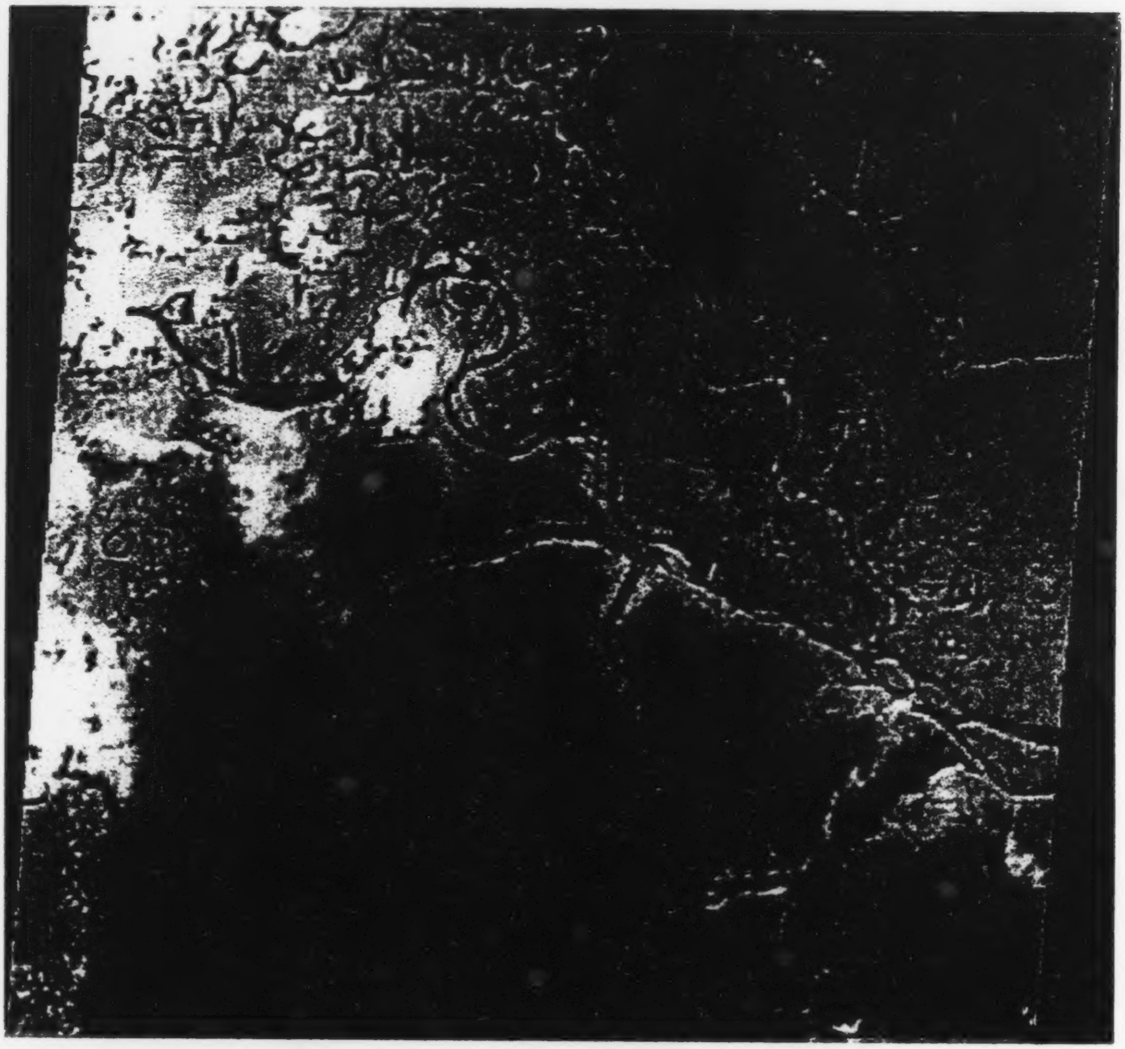
Experts agree that the number-one cause of extinction is habitat destruction. Quite simply, when habitat is reduced, species disappear. In the rainforests, logging, cattle ranching, mining, oil extraction, hydroelectric dams and subsistence farming are the leading causes of habitat destruction.

Indirectly, the leading threats to rainforest ecosystems are unbridled development, funded by international aid-lending institutions such as the World Bank, and the voracious consumer appetites of industrialized nations. If deforestation continues at current rates, scientists estimate nearly 80-90% of tropical rainforest ecosystems will be destroyed by the year 2020.

Source: Deforestation Rates in Tropical Forests and Their Climatic Implications. Rainforest Action Network Home Page: http:\\ www.ran.org/ran/info-center/rates.html

Satellite Images of Amazonia

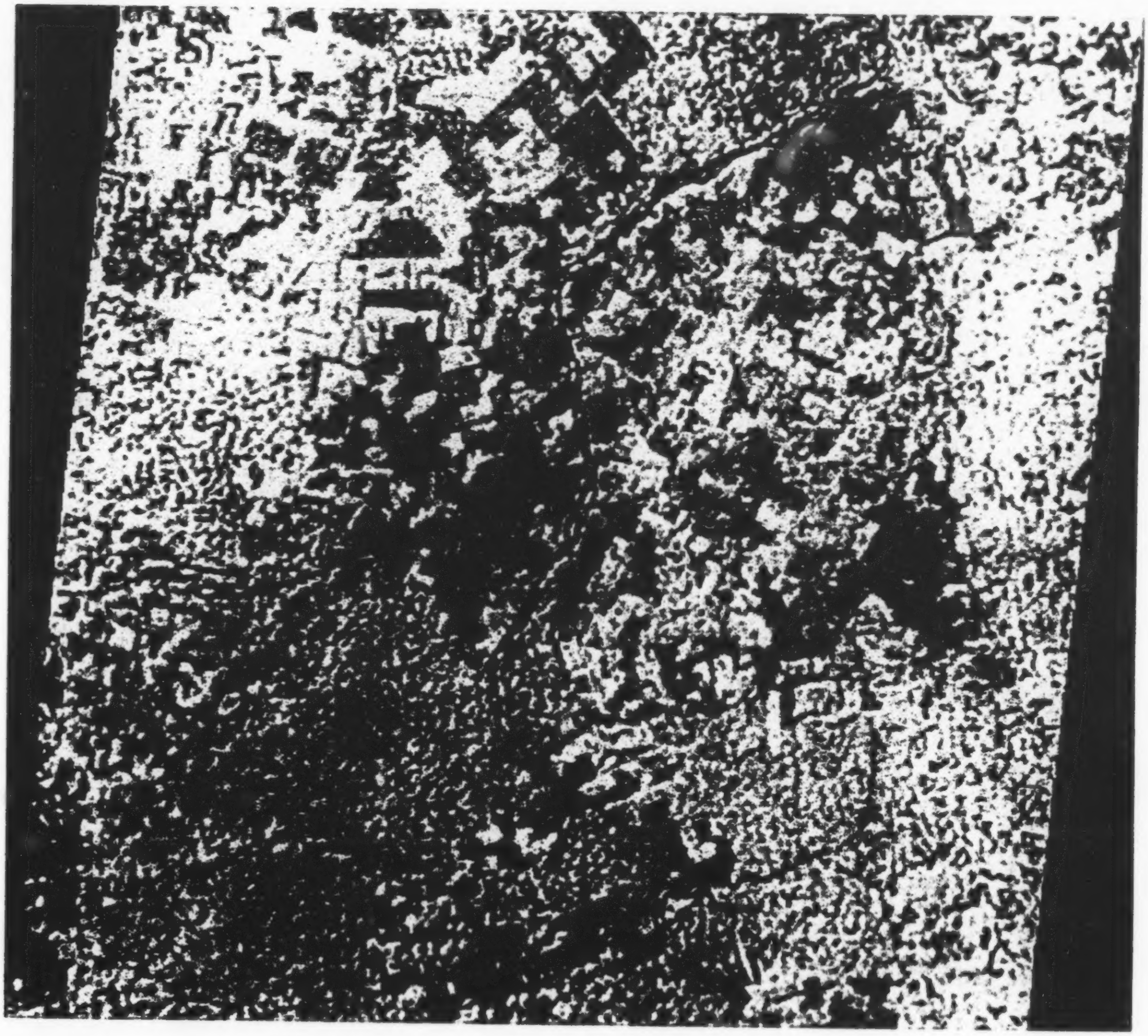
Location A



Source: This image was taken from the WWW from a sensitive map produced by the Instituto Nacional de Pesquisas Espaciasia (INPE; National Institute of Space Research) in Brazil (http://www.inpe.br/grid/quick-looks).

Satellite Images of Amazonia

Location B



Source: This image was taken from the WWW from a sensitive map produced by the Instituto Nacional de Pesquisas Espaciasia (INPE; National Institute of Space Research) in Brazil (http://www.inpe.br/grid/quick-looks).

BEST COPY AVAILABLE

GIS Images of Thailand

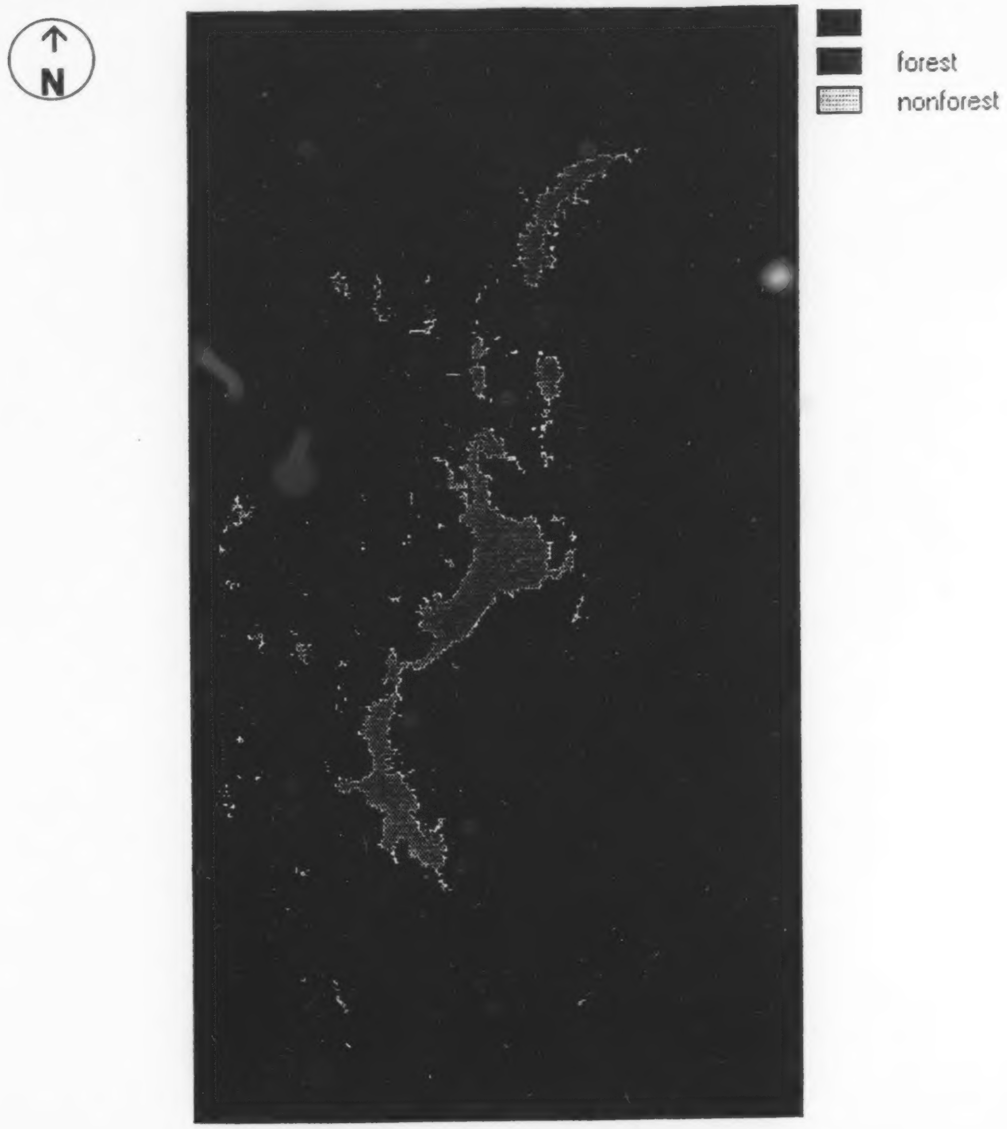
Background Information

The following two illustrations are GIS images of northern Thailand. The tropical forests of northern Thailand have been declining largely because of population pressures and the related demands for agricultural land. In response to the demand for increased agricultural production, farmers who had previously farmed the lowlands have begun to relocate onto hillside areas in search of new lands for cultivation. Forests are thus being cleared to make way for agricultural activity in these areas. The periods during which the land is allowed to lay fallow are usually not long enough for reforestation to occur.

These images were derived from the satellite series named Landsat. They were prepared by Thailand Forestry Department remote sensing experts using land use classification, meaning that the images depict areas of "forest" and "non-forest." The images show the entire Chieng-Mai Province in northwest Thailand. The province is primarily a flat plain that gives way to hilly and mountainous terrain to the west. These two images represent the same area but at two different points in time -- 1979 and 1985.

GIS Images of Thailand

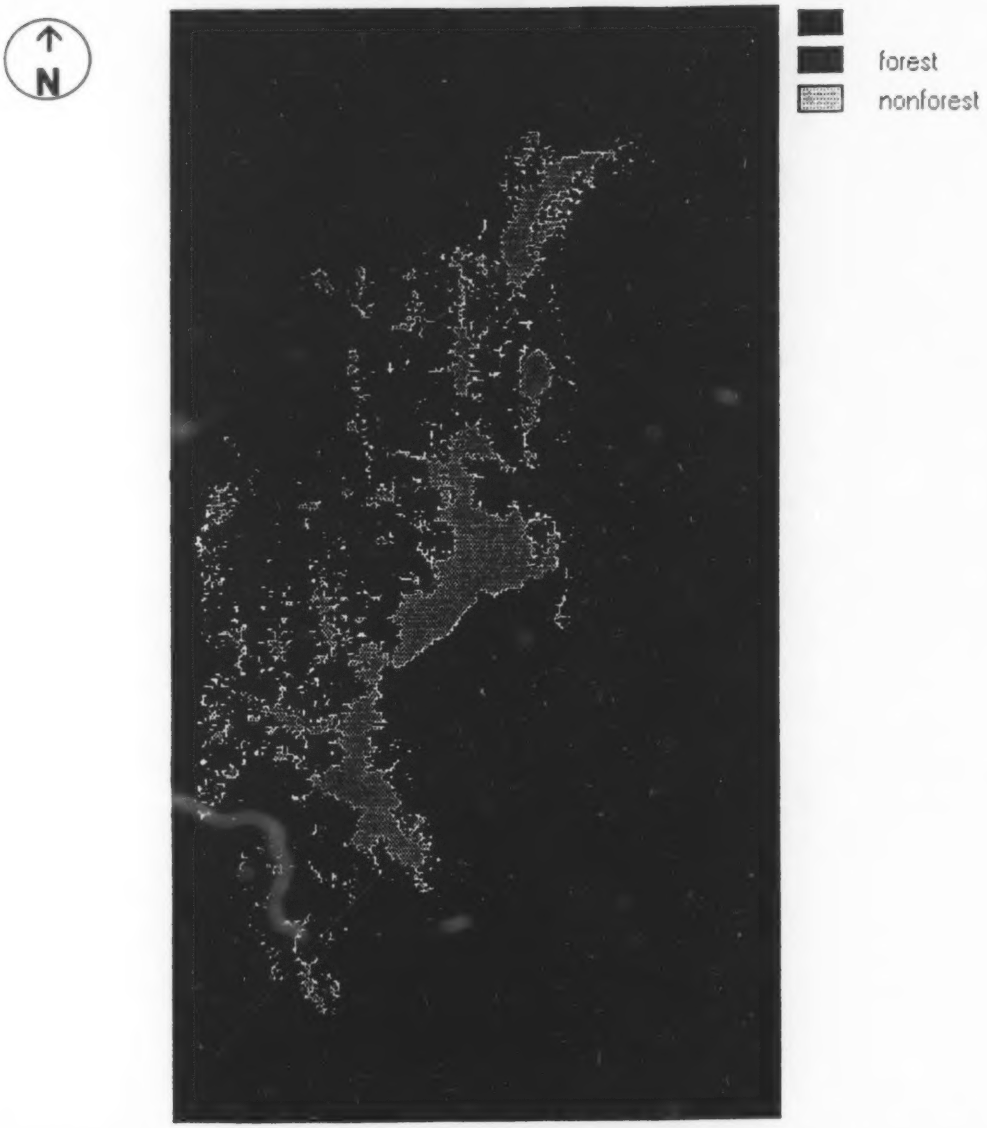
Northern Thailand, 1979



Source: McKendry, J.E., J.R. Eastman, K. St. Martin, and M.A. Fulk. 1995. *Applications in forestry. Explorations in geographic information systems technology: Volume 2.* Geneva: United Nations Institute for Training and Research. Reproduced with permission.

GIS Images of Thailand

Northern Thailand,1985



Source: McKendry, J.E., J.R. Eastman, K. St. Martin, and M.A. Fulk. 1995. *Applications in Forestry. Explorations in geographic information systems technology: Volume 2.* Geneva: United Nations Institute for Training and Research. Reproduced with permission.

Supporting Material 2.2b

BEST COPY AVAILABLE

Run-away Warming and Cooling

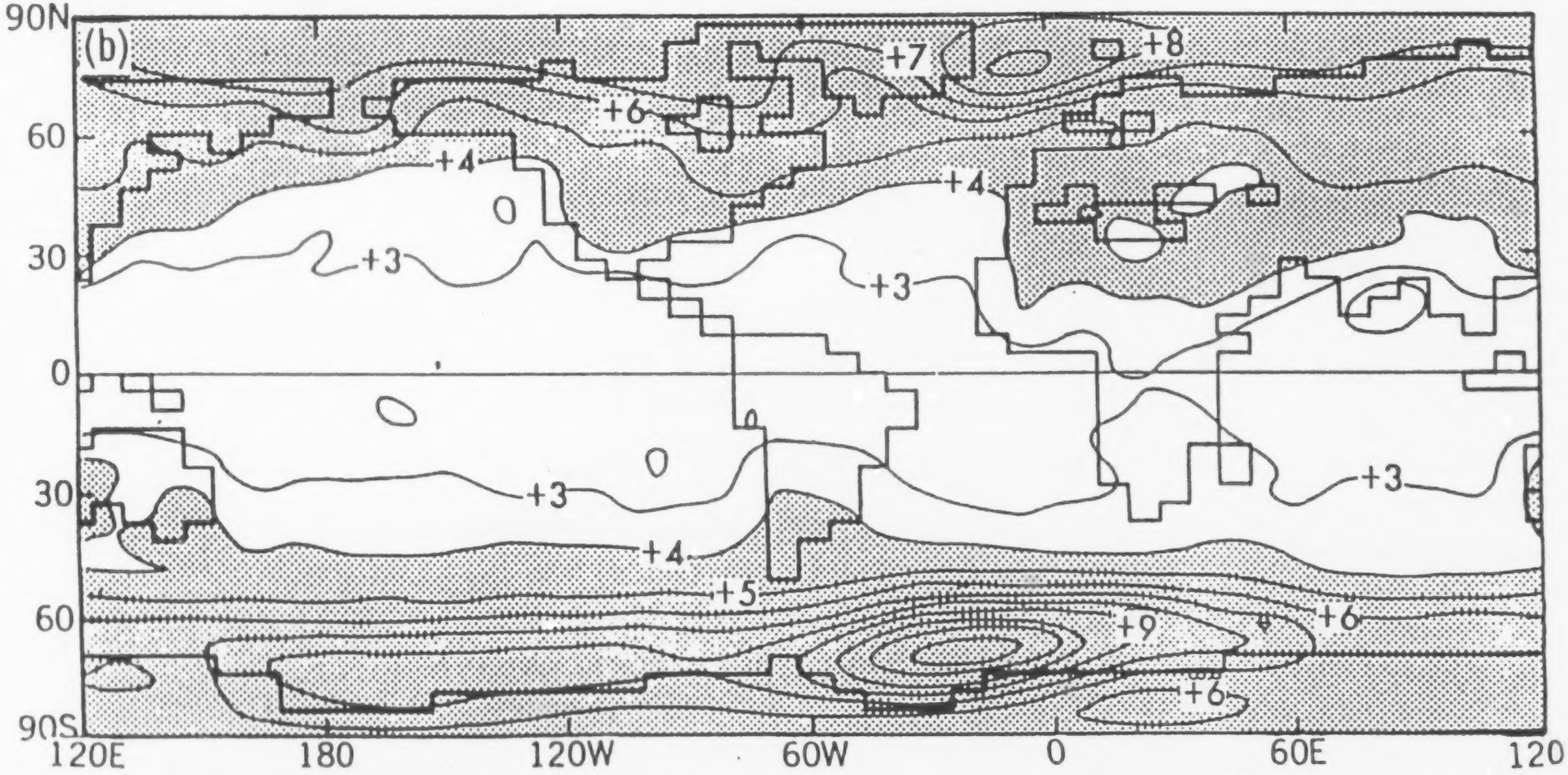
Warming Scenario: Assume that global climate change causes a warming at the poles.

Question	*What begins to happen at the poles in response to the warming?*
Answer	The snow and ice begin to melt.
Question	*What happens to the albedo or reflectivity in the region?*
Answer	It decreases.
Question	*With a lower albedo, does the region reflect or absorb more solar energy?*
Answer	It absorbs more.
Question	*What happens to the temperature in the region?*
Answer	It gets warmer.
Question	*Then what happens?*
Answer	The process begins anew.
Explanation:	This is an example of a positive feedback mechanism. It is called the ***snow-ice albedo feedback mechanism*** and it explains why scientists believe that the poles will warm more than the tropics. If the process continues, it results in run-away warming.

Cooling Scenario: Assume that global climate change causes a cooling in the mid-latitudes.

Question	*If it gets cold enough, what might occur during the winter months?*
Answer	It will snow more, or snow that occurs won't melt as quickly.
Question	What will happen to the albedo of the region?
Answer	It will increase.
Question	With a higher albedo, does the region reflect or absorb more solar energy?
Answer	It reflects more.
Question	What happens to the temperature of the region?
Answer	It cools.
Question	And then what happens?
Answer	The process begins anew .
Explanation	This is another example of a *positive feedback mechanism* in the climate system. If left unchecked, it could result in run-away cooling.

GCM Output Map: The Equilibrium Response of Surface Air Temperature to a Doubling of Atmospheric Carbon Dioxide


(b)
90N
60
30
0
30
60
90S
120E
180
120W
60W
0
60E
120
+7
+8
+6
+4
0
+3
+4
+3
0
0
+3
+3
+4
+5
+9
+6
+6

Source: Manabe, S., R. J. Stouffer, M.J. Spelman, and K. Bryan. 1991. Transient responses of a coupled-atmosphere model to gradual changes in atmospheric CO2: Part I, Annual mean response. Journal of Climate 4 (August): 796. Reprinted with the permission of the American Meteorological Society.

Legislative Hearing Stakeholders

- ***Lerr-McKee Nuclear Power Company***, a 25-year-old company that operates three nuclear power plants in the Northeast and two in the West.
- ***The United Mine Workers***, a union representing coal miners across the country.
- ***Blue Flame Federation of Natural Gas Suppliers***, a coalition of natural gas companies from across the US.
- ***The US Environmental Protection Agency***, a government organization begun in 1970 to protect the health of the country's environment
- ***Real Goods Solar Living Center***, a California-based organization that promotes solar energy use and also runs a profitable environmental goods mail-order company.
- ***Electric Utility Association***, representing electric power companies and cooperative across the country.
- ***National Academy of Sciences***, a private organization of distinguished scientists established in 1863 that acts as an official advisor to federal government on matters of science and technology.

Appendices

Appendix A: Additional Resources

Texts and Journal Articles

- IPCC (Intergovernmental Panel on Climate Change). 1996. *Climate Change 1995: The Science of Climate Change*. J.T. Houghton, L.G.M. Filho, B.A Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.). Cambridge: Cambridge University Press.

- Kasperson, J.X.., R.E. Kasperson and B.L. Turner II., eds. 1995. *Regions at risk: Comparisons of threatened environments*. Tokyo: United Nations University Press.

  A good resource for a discussion of the conceptual background to this module and case studies on various parts of the world.

- Liverman, D. M. 1990. Vulnerability to global environmental change. In R. Kasperson, K. Dow, D. Golding, and J. Kasperson, eds. *Understanding global environmental change: The contributions of risk analysis and management*. Worcester, MA: Clark University.

- Miller, G. Tyler. 1990. *Living in the environment*. Belmont: Wadsworth Publishing Company.

  A good supplementary text.

- Quayle, Robert and Thomas Karl, eds. 1996. *Climate change update: The state of the climate 1996*. A summary of the policymakers report of the IPCC. Asheville, NC: National Climatic Data Center.

- Rosenzweig, C., M.L. Parry, G. Fischer, and K. Frohberg. 1993. *Climate change and world food supply*. Research Report No. 3, Environmental Change Unit: University of Oxford.

- Stern, P.C., O.R. Young, and D. Druckman, eds. 1992. *Global environmental change: Understanding the human dimensions*. Washington, D.C.: National Academy Press.

- World Resources Institute. 1996. World Resources 1996-97. New York: Oxford University Press.

  Each year focuses on a different theme. The back of the book includes data tables on land cover, energy, population, and most other major environmental indicators.

World Wide Web Sites

This annotated list of World Wide Web resources describes sites that are related to various aspects of global environmental change research. Because sites often change, improve, or disappear over time, be sure to verify these sites before using them in the classroom.

- **Consortium for International Earth Science Information Network (CIESIN) World Data**
  http://www.ciesin.org/datasets/dataset-home.html
  This site provides a vast amount of information on the human dimensions of global change. Their mission is to make existing data available to researchers, decision makers, educators, and the public. There are interactive maps, searchable data sets, and an enormous amount of related information for both human and physical geography.

- **Climate Prediction Center**
  http://nic.fb4.noaa.gov
  Very good source for impacts-related information, including a link to the National Drought Mitigation Center. Also check out the predictions page, including the 6-10 day forecast.

- **Environmental Resources**
  http://alexia.lis.uiuc.edu/hahn/environ.html
  Links to various environmental books, journals, and other references.

- **Global Change Master Directory**
  http://gcmd.gsfc.nasa.gov
  Excellent links to major global change research sites; a particularly useful link to educational materials on earth science and global change is http://gcmd.gsfc.nasa.gov/pointers/edu.html

- **Global Environmental Change Programme**
  http://www.susx.ac.uk/Units/gec/subject.htm
  Directory of research for the Global Environmental Change Programme.

- **Global Environment Research Program**
  http://rpgopher.aist.go.jp:8000/nss/text/global.html
  Information on global warming, ozone depletion, acid rain, and marine pollution.

- **Great Global Gallery**
  http://hum.amu.edu.pl/~zbzw/glob/glob1.htm
  Excellent source of imagery for teaching purposes.

- **Greendisk**
  http://www.igc.org/greendisk
  Journal of contemporary environmental issues.

- **Intergovernmental Panel on Climate Change**
  http://www.usgcrp.gov/ipcc/html/aboutipc.html
  Access to all IPCC reports, publications, and summaries.

- **International Forest Environment Monitoring Research Team**
  http://ss.ffpri.affrc.go.jp/goin.html
  GCM output map, research program to monitor impacts of global change on forest ecosystems.

- **Mission to Planet Earth**
  http://www.hq.nasa.gov/office/mtpe
  Excellent education-related resources.

- **National Aeronautics and Space Administration (NASA)**
  http://www.nasa.gov
  The main NASA homepage with links to all of their worksites and imagery; also includes educational resources.

- **National Oceanic and Atmospheric Administration (NOAA)**
  http://www.noaa.gov
  Provides information about the agency and links to related agencies, including the National Climatic Data Center and National Oceanographic Data Center. Excellent source for satellite imagery.

- **The Rainforest Action Network**
  http://www.ran.org/ran/info-centers/rates.html

- **United States Census Data**
  http:\\www.osf.org/general/Camb/US-by-state.html
  1990 US Census population data by state

Appendix B: Suggested Readings

The AAG was able to obtain reprint permission from the original publishers for only some of the readings suggested in the activities of this module. To avoid copyright problems, we suggest you make these readings available to your students by putting them on reserve. The following readings are enclosed:

- Trenberth, K.E., J.T. Houghton, and L.G. Meira Filho. 1996. The climate system: An overview. In IPCC, *Climate change 1995: The science of climate change*. Cambridge: Cambridge University Press, pp. 55-64. © 1996 reprinted with permission of the Intergovernmental Panel on Climate Change.
- Schneider, Stephen. 1993. Degrees of certainty: *National Research Exploration* 9 (2): 173-190. ©1993 reprinted by permission of National Geographic Society. Stephen H. Schneider. *Degrees of Certainty*.

1

The Climate System: an overview

K.E. TRENBERTH, J.T. HOUGHTON, L.G. MEIRA FILHO

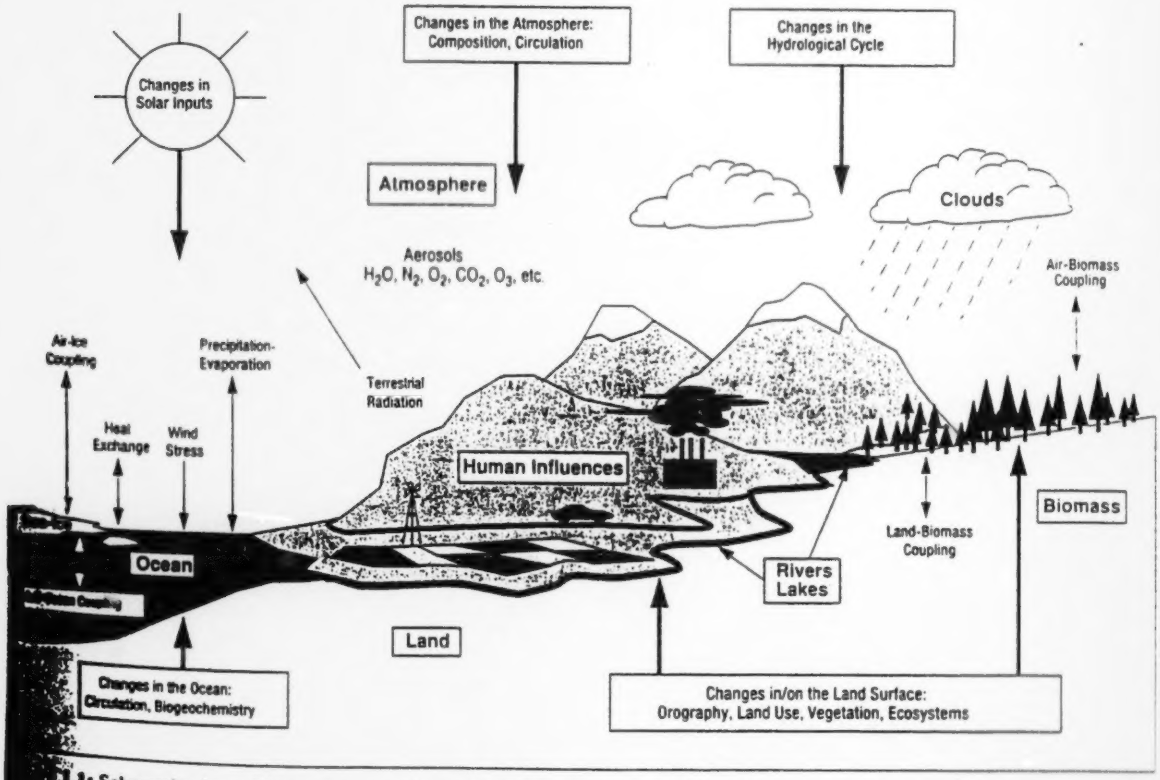
Trenberth, K.E., J.T. Houghton, and L.G. Meira Filho. 1996. The climate system: An overview. In IPCC, *Climate change 1995: The science of climate change*. Cambridge: Cambridge University Press, pp. 55-64. © 1996 reprinted with permission of the Intergovernmental Panel on Climate Change.

1.1 Climate and the Climate System

Changes in climate, whether from natural variability or anthropogenic causes and over a range of time-scales, can be identified and studied from different climate variables. Because humans live in and breathe the atmosphere it is natural to focus on the atmospheric changes where phenomena and events are loosely divided into the realms of "weather" and "climate". The large fluctuations in the atmosphere from hour-to-hour or day-to-day constitute the weather; they occur as weather systems move, develop, evolve, mature and decay as forms of atmospheric turbulence. These weather systems arise mainly from atmospheric instabilities and their evolution is governed by non-linear "chaotic" dynamics, so that they are not predictable in an individual deterministic sense beyond a week or two into the future.

Climate is usually defined to be average weather, described in terms of the mean and other statistical quantities that measure the variability over a period of time and possibly over a certain geographical region. Climate involves variations in which the atmosphere is influenced by and interacts with other parts of the climate system, and "external" forcings. The internal interactive components in the climate system (Figure 1.1) include the atmosphere, the oceans, sea ice, the land and its features (including the vegetation, albedo, biomass, and ecosystems), snow cover, land ice (including the semi-permanent ice sheets of Antarctica and Greenland and glaciers), and hydrology (including rivers, lakes and surface and subsurface water). The greatest variations in the composition of the atmosphere involve water in various phases in the atmosphere, as water vapour, clouds containing liquid water and ice crystals, and hail. However, other constituents of the atmosphere and the oceans can also change thereby bringing in considerations of atmospheric chemistry, marine biogeochemistry, and land surface exchanges.

The components normally regarded as external to the system include the Sun and its output, the Earth's rotation, Sun-Earth geometry and the slowly changing orbit, the physical components of the Earth system such as the distribution of land and ocean, the geographic features on the land, the ocean bottom topography and basin configurations, and the mass and basic composition of the atmosphere and ocean. These components determine the


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
Aerosols
H_2O, N_2, O_2, CO_2, O_3, etc.
Air-Biomass Coupling
Air-Ice Coupling
Precipitation-Evaporation
Terrestrial Radiation
Heat Exchange
Wind Stress
Human Influences
Ocean
Coupling
Biomass
Land-Biomass Coupling
Rivers Lakes
Land
Changes in the Ocean: Circulation, Biogeochemistry
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

1.1: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and pects that may change (bold arrows).

BEST COPY AVAILABLE

mean climate which may vary from natural causes. A change in the average net radiation at the top of the atmosphere due to perturbations in the incident solar radiation or the emergent infrared radiation leads to what is known as radiative forcing of the system. Changes in the incident radiation energy from the Sun or changes in atmospheric composition due to natural events like volcanoes are possible examples. Other external forcings may occur as a result of human activities, such as increases in greenhouse gases. In this report we are particularly concerned with the latter.

Changes in any of the climate system components, whether internal and thus a part of the system, or from the external forcings, cause the climate to vary or to change. Thus climate can vary because of alterations in the internal exchanges of energy or in the internal dynamics of the climate system. For example, El Niño-Southern Oscillation (ENSO) events arise from natural coupled interactions between the atmosphere and the ocean centred in the tropical Pacific. As such they are a part of climate and they lead to large and important systematic variations in weather patterns (events such as floods and droughts) throughout the world from year to year. Often, however, climate is taken to refer to much longer time-scales – the average statistics over a 30-year period is a widespread and long-standing working definition. On these longer time-scales, ENSO events vanish from mean statistics but become strongly evident in the measures of variability: the variances and the extremes. However, the mean climate is also influenced by the variability. These considerations become very important as we develop models of the climate system as tools to predict climate change.

1.2 The Driving Forces of Climate

1.2.1 The Global Energy Balance

The source of energy which drives the climate is the radiation from the Sun. Much of this energy is in the visible part of the electromagnetic spectrum although some extends beyond the red into the infrared and some extends beyond the violet into the ultraviolet. The amount of energy per second falling on a surface one square metre in area facing the Sun outside the atmosphere is about 1370 W. Because of the spherical shape of the Earth, at any one

Climate Change Definitions

Although the common definition of climate refers to the average of weather, the definition of the climate system must include the relevant portions of the broader geophysical system which increasingly interacts with the atmosphere as the time period considered increases. For the time-scales of decades to centuries associated with the change of climate due to the effect of enhanced greenhouse warming, the United Nations Framework Convention on Climate Change defines the climate system to be "the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions".

The concept of climate change has recently acquired a number of different meanings in the scientific literature and in relevant international fora. There is a simple view that climate change refers to any change of the classical 30-year climatology, regardless of its causes. Often "climate change" denotes those variations due to human interference while "climate variations" refers to the natural variations. Sometimes "climate change" designates variations longer than a certain period. Finally, "climate change" is sometimes taken in the literature to mean climate fluctuations of a global nature, which is an interpretation used in parts of this report and which includes the effects due to human actions, such as the enhanced greenhouse effect, and those due to natural causes such as stratospheric aerosols from volcanic eruptions. One complication with this definition is the anthropogenic changes of climate on a restricted space scale, a good example of which is the heat island phenomenon by which highly urbanised areas may have a mean temperature which is higher than it would otherwise have been.

Nevertheless, for the purposes of the United Nations Convention on Climate Change, the definition of climate change is: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Further, the Convention considers, for purposes of mitigation measures, only those greenhouse gases which are not controlled by the Montreal Protocol and its Amendments (i.e., ozone-depleting substances such as CFCs and the HCFCs), presumably on the grounds that the latter are covered by a separate international legal instrument. This definition thus introduces the concept of the difference between climate with the effect of human-induced increase in the concentration of greenhouse gases and that which would be realised without such human interference. This point is important scientifically for both detection and prediction because at least one of these climate states has to be modelled.

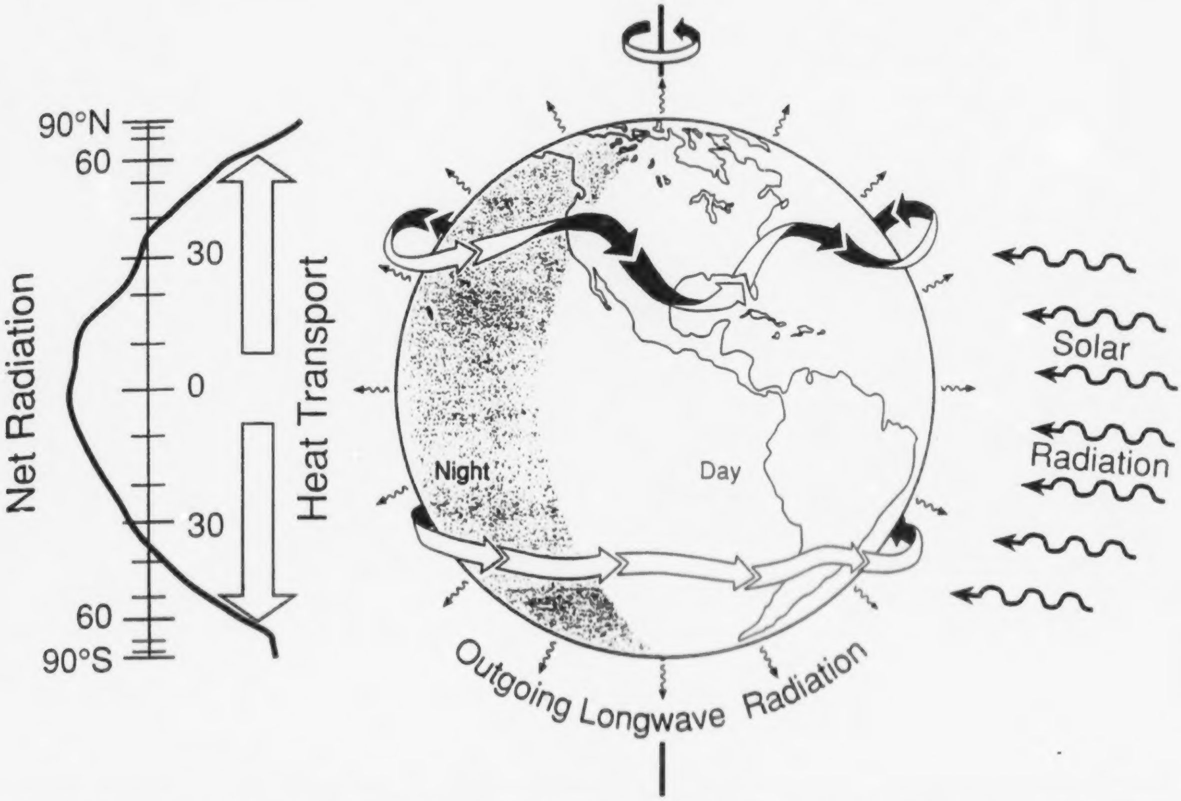


Figure 1.2: The incoming solar radiation (right) illuminates only part of the Earth while the outgoing long-wave radiation is distributed more evenly. On an annual mean basis, the result is an excess of absorbed solar radiation over the outgoing long-wave radiation in the tropics, while there is a deficit at middle to high latitudes (far left), so that there is a requirement for a poleward heat transport in each hemisphere (arrows) by the atmosphere and the oceans. This radiation distribution results in warm conditions in the tropics but cold at high latitudes, and the temperature contrast results in a broad band of westerlies in the extra-tropics of each hemisphere in which there is an embedded jet stream (shown by the "ribbon" arrows) at about 10 km above the Earth's surface. The flow of the jetstream over the different underlying surface (ocean, land, mountains) produces waves in the atmosphere and adds geographic spatial structure to climate. The excess of net radiation at the equator is 68 Wm^{-2} and the deficit peaks at -100 Wm^{-2} at the South Pole and -125 Wm^{-2} at the North Pole; from Trenberth and Solomon (1994).

ime half the Earth is in night (Figure 1.2) and the average mount of energy incident on a level surface outside the mosphere is one quarter of this or 342 Wm^{-2}. About 31% this energy is scattered or reflected back to space by olecules, microscopic airborne particles (known as rosols) and clouds in the atmosphere, or by the Earth's face, which leaves about 235 Wm^{-2} on average to warm Earth's surface and atmosphere (Figure 1.3).

o balance the incoming energy, the Earth itself must ate on average the same amount of energy back to e (Figure 1.3). It does this by emitting thermal "long- radiation in the infrared part of the spectrum. The nt of thermal radiation emitted by a warm surface ds on its temperature and on how absorbing it is. For a completely absorbing surface to emit 235 Wm^{-2} of thermal radiation, it would have a temperature of about -19°C. This is much colder than the conditions that actually exist near the Earth's surface where the annual average global mean temperature is about 15°C. However, because the temperature in the troposphere – the lowest 10-15 km of the atmosphere – falls off quite rapidly with height, a temperature of -19°C is reached typically at an altitude of 5 km above the surface in mid-latitudes.

1.2.2 *The Greenhouse Effect*

Some of the infrared radiation leaving the atmosphere originates near the Earth's surface and is transmitted relatively unimpeded through the atmosphere; this is the

BEST COPY AVAILABLE

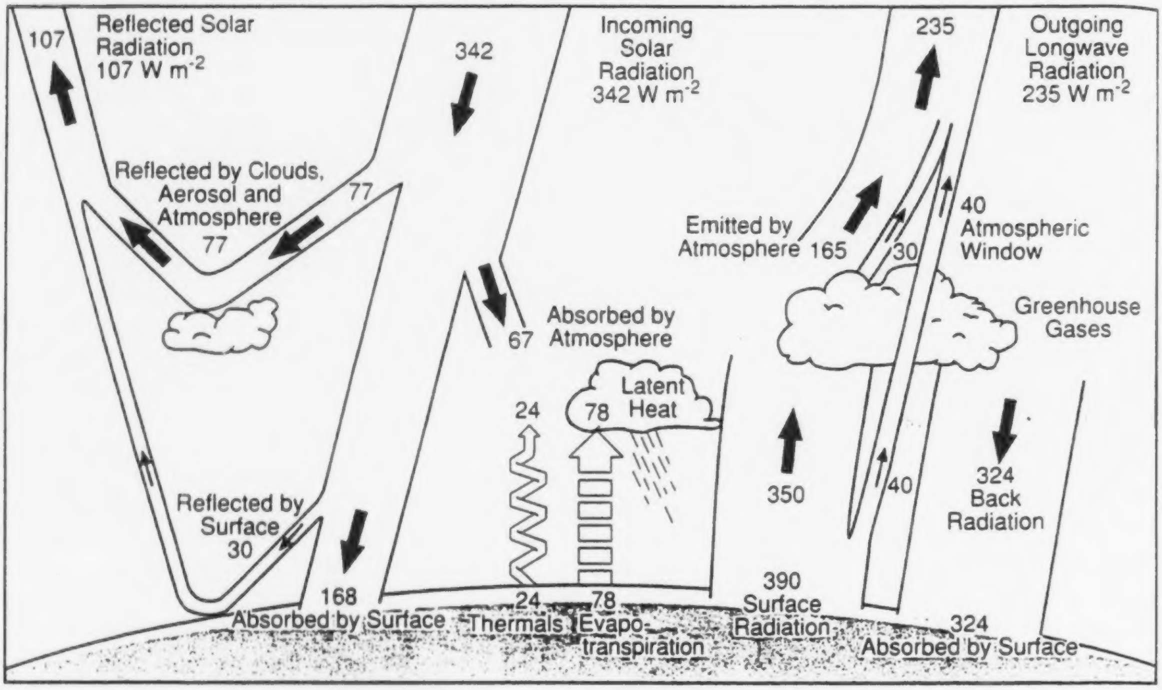

107
Reflected Solar Radiation 107 W m^{-2}
342
Incoming Solar Radiation 342 W m^{-2}
235
Outgoing Longwave Radiation 235 W m^{-2}
Reflected by Clouds, Aerosol and Atmosphere
77
77
Emitted by Atmosphere
165
30
40
Atmospheric Window
Greenhouse Gases
67
Absorbed by Atmosphere
Latent Heat
24
78
350
40
324
Back Radiation
Reflected by Surface
30
168
Absorbed by Surface
24
Thermals
78
Evapotranspiration
390
Surface Radiation
324
Absorbed by Surface

Figure 1.3: The Earth's radiation and energy balance. The net incoming solar radiation of 342 Wm^{-2} is partially reflected by clouds and the atmosphere, or at the surface, but 49% is absorbed by the surface. Some of that heat is returned to the atmosphere as sensible heating and most as evapotranspiration that is realised as latent heat in precipitation. The rest is radiated as thermal infrared radiation and most of that is absorbed by the atmosphere which in turn emits radiation both up and down, producing a greenhouse effect, as the radiation lost to space comes from cloud tops and parts of the atmosphere much colder than the surface. The partitioning of the annual global mean energy budget and the accuracy of the values are given in Kiehl and Trenberth (1996).

radiation from areas where there is no cloud and which is present in the part of the spectrum known as the atmospheric "window" (Figure 1.3). The bulk of the radiation, however, is intercepted and absorbed by the atmosphere which in turn emits radiation both up and down. The emissions to space occur either from the tops of clouds at different atmospheric levels (which are almost always colder than the surface), or by gases present in the atmosphere which absorb and emit infrared radiation. Most of the atmosphere consists of nitrogen and oxygen (99% of dry air) which are transparent to infrared radiation. It is the water vapour, which varies in amount from 0 to about 2%, carbon dioxide and some other minor gases present in the atmosphere in much smaller quantities which absorb some of the thermal radiation leaving the surface and emit radiation from much higher and colder levels out to space. These radiatively active gases (see Chapter 2 for details) are known as greenhouse gases because they act as a partial blanket for the thermal radiation from the surface and enable it to be substantially warmer than it would otherwise be, analogous to the effects of a greenhouse. This blanketing is known as the natural greenhouse effect.

Clouds also absorb and emit thermal radiation and have a blanketing effect similar to that of the greenhouse gases. But clouds are also bright reflectors of solar radiation and thus also act to cool the surface. While on average there is strong cancellation between the two opposing effects of short-wave and long-wave cloud radiative forcing (Chapter 4) the net global effect of clouds in our current climate, as determined by space-based measurements, is a small cooling of the surface.

1.2.3 Mars and Venus

Similar greenhouse effects also occur on our nearest planetary neighbours, Mars and Venus. Mars is smaller than the Earth and possesses, by Earth's standards, a very thin atmosphere (the pressure at the Martian surface is less than 1% of that on Earth) consisting almost entirely of carbon dioxide which contributes a small but significant greenhouse effect. The planet Venus, by contrast, has a

BEST COPY AVAILABLE

much thicker atmosphere, largely composed of carbon dioxide, with a surface pressure nearly 100 times that on Earth. The resulting greenhouse effect on Venus is very large and leads to a surface temperature of about 500°C more than it would otherwise be.

1.2.4 Spatial Structure of Climate and Climate Change

For the Earth, on an annual mean basis, the excess of solar over outgoing long-wave radiation in the tropics and the deficit at mid- to high latitudes (Figure 1.2) sets up an equator-to-pole temperature gradient that results, with the Earth's rotation, in a broad band of westerlies in each hemisphere in the troposphere. Embedded within the mid-latitude westerlies are large-scale weather systems which, along with the ocean, act to transport heat polewards to achieve an overall energy balance. These weather systems are the familiar migrating cyclones and anticyclones (i.e., low and high pressure systems) and their associated cold and warm fronts.

Because of the land-ocean contrasts and obstacles such as mountain ranges, the mid-latitude westerlies and the embedded jet stream (Figure 1.2) in each hemisphere contain planetary-scale waves. These waves are usually geographically anchored but can change with time as heating patterns change in the atmosphere. A consequence is that anomalies in climate on seasonal-to-annual time-scales typically occur over large geographic regions with surface temperatures both above and below normal in different places. An example for the Northern Hemisphere winter season, December 1993 to February 1994, is shown in Figure 1.4. The strong cold anomaly over north-eastern parts of North America was accompanied by many cold and snowy outbreaks, yet warmer-than-normal conditions prevailed over most of the rest of the hemisphere. Relative to 1951 to 1980, the result was a hemispheric anomaly in surface temperature of +0.2°C. Extensive regions of above and below normal temperatures are the rule, not the exception, as should clearly be expected from the wave motions in the atmosphere. A bout of below average temperatures regionally may not be inconsistent with global warming, just as an interval of above normal temperatures may not indicate global warming.

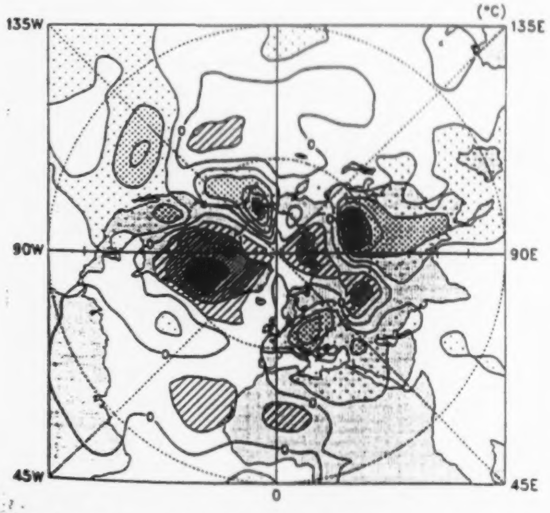


Figure 1.4: The anomalies in surface temperature over the Northern Hemisphere for the winter of December 1993 to February 1994 relative to the mean for 1951 to 1980. Temperature anomalies exceeding 1°C are stippled and those below −1°C are hatched. The spatial structure seen here is inherent in the atmospheric dynamics and regions of below-normal temperatures should be expected even in the presence of an overall mean that is 0.2°C above normal. Data courtesy of David Parker.

1.3 Anthropogenic Climate Change

Climate can vary for many reasons. In particular, human activities can lead to changes in atmospheric composition and hence radiative forcing through, for instance, the burning of fossil fuels or deforestation, or through processes which increase the number and distribution of aerosols. Altered properties of the surface because of changes in land-use can also give rise to changes in climate. It is especially these effects due to human activities with which we are concerned in this report.

1.3.1 The Enhanced Greenhouse Effect

The amount of carbon dioxide in the atmosphere has increased by more than 25% in the past century and since the beginning of the industrial revolution, an increase which is known to be in large part due to combustion of fossil fuels and the removal of forests (Chapter 2). In the absence of controls, projections are that the future rate of increase in carbon dioxide amount may accelerate and concentrations could double from pre-industrial values within the next 50 to 100 years (IPCC, 1994).

The increased amount of carbon dioxide is leading to climate change and will produce, on average, a global warming of the Earth's surface because of its enhanced greenhouse effect – although the magnitude and significance of the effects are not yet fully resolved. If, for instance, the amount of carbon dioxide in the atmosphere were suddenly doubled, but with other things remaining the same, the outgoing long-wave radiation would be reduced by about 4 Wm^{-2}. To restore the radiative balance, the atmosphere must warm up and, in the absence of other changes, the warming at the surface and throughout the troposphere would be about 1.2°C. However, many other factors will change, and various feedbacks come into play (see Section 1.4.1), so that the best estimate of the average global warming for doubled carbon dioxide is 2.5°C (IPCC, 1990). Such a change is very large by historical standards and would be associated with major climate changes around the world.

Note that if the carbon dioxide were removed from the atmosphere altogether, the change in outgoing radiation would be about 30 Wm^{-2} – 7 or 8 times as big as the change for doubling – and the magnitude of the temperature change would be similarly enhanced. The reason is that the carbon dioxide absorption is saturated over part of the spectral region where it absorbs, so that the amount of absorption changes at a much smaller rate than the concentration of the gas (Chapter 2). If concentrations of carbon dioxide are more than doubled, then the relationship between radiative forcing and concentration is such that each further doubling provides a further radiative forcing of about 4 Wm^{-2}.

Several other greenhouse gases are also observed to be increasing in concentration in the atmosphere because of human activities (especially biomass burning, landfills, rice paddies, agriculture, animal husbandry, fossil fuel use and industry). These include methane, nitrous oxide, and tropospheric ozone, and they tend to reinforce the changes in radiative forcing from increased carbon dioxide (Chapter 2). The human-introduced chlorofluorocarbons (CFCs) also produce a greenhouse effect although offset somewhat by the observed decreases in lower stratospheric ozone since the 1970s, caused principally by the CFCs and halons (IPCC, 1994).

1.3.2 Effects of Aerosols

Human activities also affect the amount of aerosol in the atmosphere which influences climate in other ways. The main direct effect of aerosols is the scattering of some solar radiation back to space, which tends to cool the Earth's surface. Some aerosols can also influence the radiation budget by directly absorbing solar radiation leading to local heating of the atmosphere and, to a lesser extent, by absorbing and emitting thermal radiation. A further influence of aerosols is that many of them act as nuclei on which cloud droplets condense. A changed concentration therefore tends to affect the number and size of droplets in a cloud and hence alters the reflection and the absorption of solar radiation by the cloud.

Aerosols occur in the atmosphere from natural causes; for instance, they are blown off the surface of deserts or dry regions. The eruption of Mt. Pinatubo in the Philippines in June 1991 added considerable amounts of aerosol to the stratosphere which, for about two years scattered solar radiation leading to a loss of radiation at the surface and a cooling there. Human activities contribute to aerosol particle formation mainly through injection of sulphur dioxide into the atmosphere (which contributes to acid rain) particularly from power stations, and through biomass burning.

Because human-made aerosols typically remain in the atmosphere for only a few days they tend to be concentrated near their sources such as industrial regions. The radiative forcing therefore possesses a very strong regional pattern (Chapters 2, 6 and 8), and the presence of aerosols adds further complexity to possible climate change as it can help mask, at least temporarily, any global warming arising from increased greenhouse gases. However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result.

1.4 Climatic Response

1.4.1 Feedbacks

The increases in greenhouse gases in the atmosphere and changes in aerosol content produce a change in the radiative forcing (Chapter 2). The determination of the climatic response to this change in forcing is complicated by feedbacks. Some of these can amplify the original warming (positive feedback) while others serve to reduce it (negative feedback) (Chapter 4). An example of the former is water vapour feedback in which the amount of water vapour in the atmosphere increases as the Earth warms and, because water vapour is an important greenhouse gas, it will amplify the warming. However, increases in cloud may act either to amplify the warming through the greenhouse effect of clouds or reduce it by the increase in albedo (which measures reflectivity); which effect dominates depends on the height and type of clouds and varies greatly with geographic location and time of year. Ice-albedo feedback is another potentially important process that may lead to amplification of temperature changes in high latitudes. It arises because decreases in sea ice, which has high albedo, decrease the radiation reflected back to space and thus produces warming which may further decrease the sea ice extent. However, increased open water may lead to more atmospheric water vapour and increased fog and low cloud amount, offsetting the change in surface albedo.

There are a number of feedbacks involving the biosphere which are especially important when considering details of

BEST COPY AVAILABLE

the carbon cycle and the impacts of climate change. The behaviour of ecosystems on the surface of the Earth (Chapter 9) and biogeochemical processes within the oceans (Chapters 2 and 10) are greatly influenced by changes in atmospheric composition and climate. The availability of surface water and the use of the Sun's energy in photosynthesis and transpiration in plants influence the uptake of carbon dioxide from the atmosphere as plants transform the carbon and water into usable food. Changes in vegetation affect surface albedo, evapotranspiration and roughness. Much remains to be learned about these feedbacks and their possible influences on predictions of future carbon dioxide concentrations and climate, and models used for future projections have not yet incorporated them.

1.4.2 The Role of the Oceans

The oceans cover 70% of the Earth's surface and through their fluid motions, their high heat capacity, and their ecosystems they play a central role in shaping the Earth's climate and its variability. Wind stress at the sea surface drives the large-scale ocean circulation in its upper layers. Water vapour, evaporated from the ocean surface, provides latent heat energy to the atmosphere. The ocean circulation is an effective means of redistributing heat and fresh water around the globe. The oceans store heat, absorbed at the surface, for varying durations and release it in different places thereby ameliorating temperature changes over nearby land and contributing substantially to the variability of climate on many time-scales. Additionally, the ocean thermohaline[1] circulation allows water from the surface to be carried into the deep ocean where it is isolated from atmospheric influence and hence it may sequester heat for periods of a thousand years or more. The oceans absorb carbon dioxide and other gases and exchange them with the atmosphere in ways that alter with ocean circulation and climate variability. In addition, it is likely that marine biotic responses to climate change will result in feedbacks (Chapter 10).

Any study of the climate and how it might change must include an adequate description of processes in the ocean (Chapter 4) together with the coupling between the ocean and the atmosphere (Chapter 6).

1.4.3 The Role of Land

The heat penetration into land associated with the annual cycle of surface temperature is limited to about the uppermost 2 m and the heat capacity of land is much less than that of a comparable depth of ocean. Accordingly, land plays a much smaller role in the storage of heat. A consequence is that the surface air temperature changes over land occur much faster and are much larger than over the oceans for the same heating and, because we live on land, this directly affects human activities. The land surface encompasses an enormous variety of topographical features and soils, differing slopes (which influence runoff and radiation received) and water capacity. The highly heterogeneous vegetative cover is a mixture of natural and managed ecosystems that vary on very small spatial scales. Changes in soil moisture affect the disposition of heat and whether it results in sensible heating or evapotranspiration (and subsequently latent heating) and changes in vegetation alter the albedo, roughness, and evapotranspiration. The land surface and its ecosystems play an important role in the carbon cycle (Chapter 9), the hydrological cycle and in surface exchanges of trace gases. Currently, many of these land surface processes are only crudely represented in global climate models.

1.5 Observed Climate Change

Given that climate change is expected from anthropogenic effects, what have the observed changes been? Because the high quality of much-needed long time-series of observations is often compromised, special care is required in interpretation. Most observations have been made for other purposes, such as weather forecasting, and therefore typically suffer from changes in instrumentation, exposure, measurement techniques, station location and observation times, and there have been major changes in the distribution and numbers of observations. Adjustments must be devised to take into account all these influences in estimating the real changes that have occurred. For the more distant past, proxy data from climate-sensitive phenomena, such as from tree rings, ice cores, coral cores, and pollen in marine sediments are used.

Questions of how the climate has varied in the past, whether there has been recent warming and the structure of climate change in three dimensions are addressed in Chapter 3. Analysis of observations of surface temperature show that there has been a global mean warming of 0.3 to 0.6°C over the past one hundred years. The observed trend of a larger increase in minimum than maximum temperatures is apparently linked to associated increases in low cloud amount and aerosol as well as to the enhanced greenhouse effect (Chapters 3 and 4). There is good evidence for decadal changes in the atmospheric circulation which contribute to regional effects, and some

---

[1] The circulation driven by changes in sea water density arising from temperature (thermal) or salinity (haline) effects.

BEST COPY AVAILABLE

evidence for ocean changes. Changes in precipitation and other components of the hydrological cycle vary considerably geographically. Changes in climate variability and extremes are beginning to emerge, but global patterns are not yet apparent.

Changes in climate have occurred in the distant past as the distribution of continents and their landscapes have changed, as the so-called Milankovitch changes in the orbit of the Earth and the Earth's tilt relative to the ecliptic plane have varied the insolation received on Earth, and as the composition of the atmosphere has changed, all through natural processes. Recent new evidence from ice cores drilled through the Greenland ice sheet have indicated that changes in climate may often have been quite rapid and large, and not associated with any known external forcings. Understanding the spatial scales of this variability and the processes and mechanisms involved is very important as it seems quite possible that strong nonlinearities may be involved. These may result in large changes from relatively small perturbations by provoking positively reinforcing feedback processes in the internal climate system. Changes in the thermohaline circulation in the Atlantic Ocean are one way such abrupt changes might be realised (Chapters 4 and 6). An important question therefore is whether there might be prospects for major surprises as the climate changes.

Rates of change of radiative forcing induced by human activities are exceedingly rapid compared with the historical record. This raises questions about how, for instance, surface ecosystems might adapt to such change (Chapter 9).

1.6 Prediction and Modelling of Climate Change

To quantify the response of the climate system to changes in forcing it is essential to account for all the complex interactions and feedbacks among the climate system components (Figure 1.1). It is not possible to do this reliably using empirical or statistical models because of the complexity of the system, and because the possible outcomes may go well beyond any conditions ever experienced previously. Instead the response must be found using numerical models of the climate system based upon sound well-established physical principles.

1.6.1 Climate Models

Global climate models include as central components atmospheric and oceanic general circulation models (GCMs), as well as representations of land surface processes, sea ice and all other processes indicated in Figure 1.1. Models and their components are based upon physical laws represented by mathematical equations th describe the atmospheric and oceanic dynamics an physics. These equations are solved numerically at a fini resolution using a three-dimensional grid over the glob Typical resolutions used for climate simulations in 19 are about 250 km in the horizontal and 1 km in the vertic in atmospheric GCMs. As a result, many physic processes cannot be properly resolved but their averag effects must be included through a parametr representation (called parametrization) that is physicall based (Chapter 4).

An essential component of climate models is th description of the interactions among the differe components of the climate system. Of particul importance is the coupling between the two flu components, the atmosphere and the ocean. Ensuring this adequately simulated is one of the greatest challenges climate modelling (Chapter 4). A frontier and futur research challenge is to bring more complete chemistr biology, and ecology into the climate system mode (Chapters 9, 10, and 11) and to improve the representatio of physical processes. Once validated, these models wi become valuable tools for advancing our understandin and quantifying and reducing the uncertainty in futur predictions.

Comprehensive climate models are very complex an take large computer resources to run. To explore all th possible scenarios and the effects of assumptions approximations in parameters in the model mor thoroughly, simpler models are also widely used and a constructed to give similar results to the GCMs whe globally averaged (Chapter 6).

1.6.2 Climate Predictability

An important and fundamental question concerns th extent to which the climate is predictable; i.e., are the climate "signals" large enough to be distinguished from th "noise" of natural variability that may be potentiall predictable. Reliable weather forecasts can be made usin atmospheric GCMs for periods up to ten days (Chapter 5 beyond which time detailed predictability is lost because the dominance of chaotic dynamics in weather system For some parts of the world, however, some predictabili exists for statistical averages of weather (i.e., the climat up to a year or so ahead. Such predictability is largely du to the influence of the patterns of sea surface temperatur on the atmosphere. El Niño events provide the domina example. Prediction of changes in sea surface temperatur in turn requires that climate models be able to adequate simulate the coupling between ocean and atmosphere.

The predictability considered so far concerns the internal variability. Climate changes arising from changes in external forcing can also be predictable, as is evidenced from several sources. Firstly, there is the mean annual cycle which climate models simulate very well. Secondly, there is the existence of the regularities observed in past climates which were forced by changes in the distribution of solar radiation arising from the variations in the geometry of the Sun-Earth orbit. Models show some success in simulating these past climates. Thirdly, there is the success of climate models in simulating the changes due to the effects of stratospheric aerosols from the Mt. Pinatubo volcanic eruption. In addition, there is the evidence provided by the performance of the models themselves in simulating the effects of hypothetical situations, such as changes in solar radiation; the resulting climate changes are largely reproducible and thus potentially predictable.

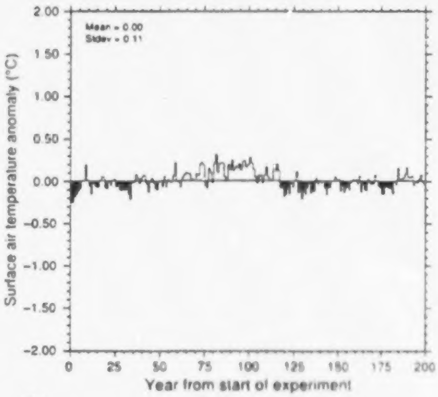
Predictability is a function of spatial scales. Atmospheric variability arising from internal instabilities is huge on small scales; it is mainly the variability on larger scales influenced by the interactions of the atmosphere with other parts of the climate system that is predictable. Figure 1.5 shows the natural variability of the annual mean surface temperature on several different spatial scales from a climate model simulation for 200 years. The vertical scale is the same on all three plots, and the standard deviation goes from 0.1°C for the Southern Hemisphere to 0.5°C for Australia to 0.8°C for a grid square with sides about 500 km in south-east Australia. This example highlights the much greater natural variability that can be experienced on smaller scales which makes detection of the small systematic signal, such as might arise from enhanced global mean greenhouse forcing, much more difficult to achieve on regional scales.

[illegible].3 *Climate Projections*

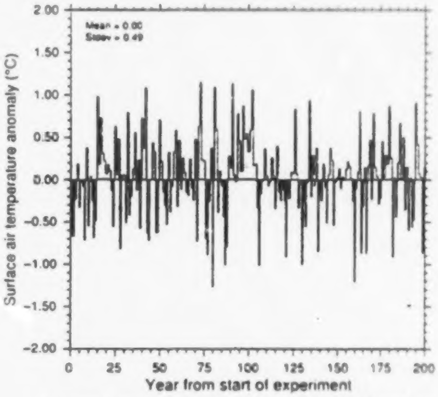
When a model is employed for climate prediction it is first run for many simulated decades without any changes in external forcing in the system. The quality of the simulation can then be assessed by comparing the mean, the annual cycle and the variability statistics on different time-scales with observations of the climate. In this way the model is evaluated (Chapter 5). The model is then run with changes in external forcing, such as with a possible future profile of greenhouse gas concentrations (Chapter 2). The differences between the climate statistics in the two simulations provide an estimate of the accompanying climate change (Chapter 6).

A long-term change in global mean surface air temperature arising from a doubling of carbon dioxide is

(a) Southern Hemisphere



(b) Australia



(c) Single model grid box in south-east Australia

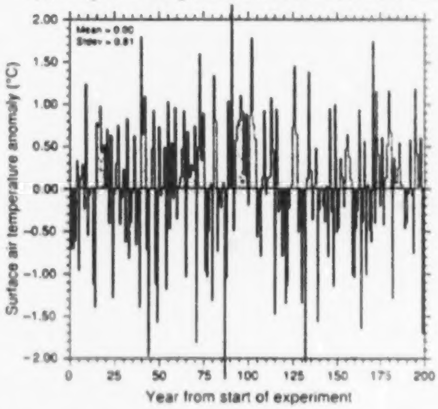


Figure 1.5: Annual-average surface air temperature (°C) from a 200-year integration of a coupled atmosphere-ocean model from the Geophysical Fluid Dynamics Laboratory run at low resolution of about 500 km spacing. The model is in statistical equilibrium and has no trends in climate forcing applied. The three panels show results for (a) the Southern Hemisphere, (b) Australia, and (c) a grid box in south-east Australia. (Courtesy J. Mahlman, S. Manabe, T. Delworth and R. Stouffer).

often used as a benchmark to compare models and as an indication of the climate sensitivity of the models. The range of results is typically an increase of 1.5° to 4.5°C. However, the concentrations of greenhouse gases will not level off at doubling and the regional patterns of climate change depend significantly on the time dependence of the change in forcing. It is important, therefore, to make future projections using plausible evolving scenarios of anthropogenic forcing so that the response of the climate to the forcing is properly simulated.

Accordingly, the focus of Chapter 6 is on projections of future climate using possible scenarios of greenhouse gas and aerosol emissions. Because of uncertainties in the scenarios, it is worth noting that these outlooks are not predictions so much as climate change estimates which can be used to assess possible impacts on the environment and society (IPCC Working Group II), such as the changes in sea level (Chapter 7), and for planning and policy purposes (IPCC Working Group III). However, definitive projections of possible local climate changes, which are most needed for assessing impacts, are the most challenging to do with any certainty. Further, it is desirable to examine and evaluate the past observational record by running models forced with realistic radiative forcing. It is in this way that it may be possible to attribute the observed changes to particular changes in forcing, such as from volcanic or solar origins, and to achieve detection of the effects of human activities and specifically the effects fro increases in aerosols and greenhouse gases (Chapter 8).

The models used in climate projections are valuab tools for helping to quantify possible outcomes und various scenarios. They are used with the observations a all the other evidence to make the best assessmen possible. The models are still undergoing development a their capabilities will improve in the future as past and ne observations are analysed and improved understanding obtained.

References

IPCC (Intergovernmental Panel on Climate Change), *199 Climate Change: The IPCC Scientific Assessment*, J. Houghton, G.J. Jenkins and J.J. Ephraums (eds.). Cambridg University Press, Cambridge, UK, 365 pp.

IPCC, 1994: *Climate Change 1994. Radiative Forcing of Clima Change and an Evaluation of the IPCC IS92 Emissio Scenarios*. J.T. Houghton, L.G. Meira Filho, J. Bruce, H. Le B.A. Callander, E. Haites, N. Harris and K. Maskell (eds) Cambridge University Press, Cambridge, UK, 339 pp.

Kiehl, J.T. and K.E. Trenberth, 1996: Earth's annual global mea energy budget. *Bull. Am. Met. Soc.* (submitted).

Trenberth, K.E. and A. Solomon, 1994: The Global Hea Balance: Heat transports in the atmosphere and ocean. *Clim Dyn.*, **10**, 107–134.

BEST COPY AVAILABLE

Degrees of Certainty

STEPHEN H SCHNEIDER

Debate in the media over global warming often mixes what is well known with what is speculative, thereby leading to an artificially confusing impression that scientists share no consensus of the probable magnitude, timing, and potential seriousness of the environmental and societal consequences of the documented and well-understood buildup of various greenhouse-enhancing gases in the atmosphere. Indeed, widespread concern exists over the plausibility of temperature increases of 1 to 5°C in the 21st century, and that the mid to upper part of that range could imply dramatic restructuring of ecosystems or communities. I discuss the difficulty in interpreting the 0.5 ± 0.2°C 20th century warming trend as "proof" of greenhouse-gas–induced global warming in light of possible climatic-change causal factors such as industrial aerosols, natural fluctuations, or changes in solar output. How to act is controversial, and economic model results showing potential abatement costs of carbon taxes are discussed.

SCIENTISTS TOO OFTEN SHARE RESPONSIBILITY with the media for not clearly communicating complex science issues to the public. Most members of the general public, as well as many officials in government, do not recognize that most scientists spend the bulk of their time arguing about what they do not know. Most scientists consider discussions of well-accepted, proven ideas as "old hat" and not worth our time. That attitude is not without merit, however, for the scientific method operates on the basis of constant questioning, particularly for issues that are not yet well-validated. But if the public and its representatives do not understand our process and its focus on not-yet-resolved issues, they will not easily interpret what has been called the "dueling scientists" debate over global warming, regardless of whether the scientists are ideologically driven. We simply have to spend more time making clear the distinctions among what is well-known and accepted by most knowledgeable scientists, what is known with some degree of reliability, and what is highly speculative.

The public debate on global warming rarely separates those components, thereby leaving the false impression that somehow the scientific community is in overall intellectual disarray. In fact, the 15-year-old often-reaffirmed U S National Academy of Sciences consensus estimate of 1.5 to 4.5°C global average warming if CO_2 were to double still reflects the best estimate from a wide range of current climate models[8] and ancient climatic eras.[7] The Earth has not been >1 to 2°C warmer than now during the 10 000-year era of human civilization. The previous ice age, in which mile-high ice sheets stretched from New York to Chicago to the Arctic, was "only" 5°C colder than the current 10 000-year-old interglacial epoch we now enjoy. This 1.5 to 4.5°C warming range still includes those studies that recently halved the best guess on warming from >4°C to 2.5°C. Perhaps some new discovery next week will push it back up again, but even if not, that enduring 1.5 to 4.5°C warming consensus still remains.

Changes of this magnitude could dramatically alter accustomed climatic patterns, affecting agriculture, water supplies, disease patterns, ecosystems, endangered species, severe storms, sea level, and coastal flooding.

Unless scientists communicate what they know along with what they do not know, the public policy process is subverted in an endlessly confusing debate that inadequately represents the actual nature of informed opinion. It is difficult for the media to do what sometimes I wish they would: back off their concept of "balance" in favor of the concept of "perspective." If an issue is complicated, it is not enough to give equal inches or minutes to "all sides"—a practice that often leaves the public more confused than before,

©1993 reprinted by permission of National Geographic Society. Stephen H. Schneider. *Degrees of Certainty*.

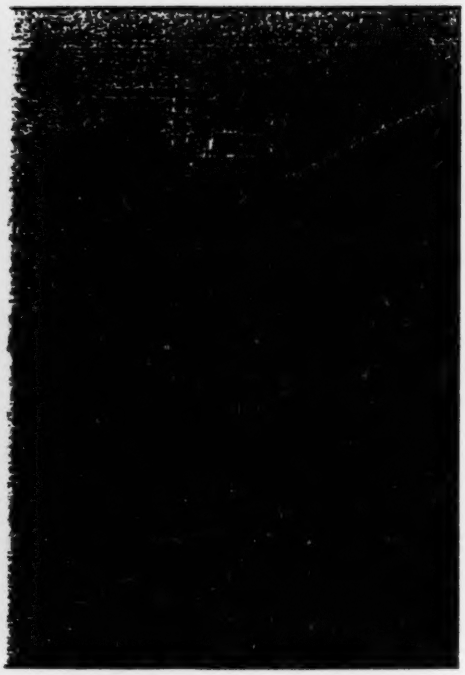


Figure 1.
Qingdao, Shandong Province, People's Republic of China, 1987. In 1898, China ceded Qingdao to Germany for 99 years, along with the right to build the Shandong railway and to work the coal mines for 14 km on either side of the railway line.
BRUCE DALE

particularly if the "sides" that are left out are the middle: the bulk of experts, ie, the people who created the established consensus.

Moreover, that established consensus must be stated in terms of probabilities, because very few scientists—myself included—would say they believe the future climate will be in or out of the 1.5 to 4.5°C warming range for certain. Rather, most believe this range to be reasonably probable. Therefore, if scientific opinion is to be communicated accurately, it must be by converting issues into probabilistic terms and providing perspective on the range of views rather than by conducting an entertaining but misleading debate among the most extreme of the dueling scientists—or occasionally stretched beyond caricature in editorials or articles by polemicists and ideologues. What counts, then, is the nature of the evidence and the spectrum of opinions of a broadly representative group of experts,[eg 8,13] not simply a few highly visible debaters with extreme views.

What Does Comprise a Consensus on Global Warming?

Just to illustrate the point that much is already known, I offer the following list of global-warming–related points accepted by a very large fraction of the relevant expert communities. One good source for discussion on the following points is the recent National Research Council's study on global warming and its implications.[13] (Following each of these statements is my own estimate of the likelihood of the statement turning out to be true.)

- ► GREENHOUSE GASES—H_2O, CO_2, CH_4, N_2O, CFC—trap infrared radiative energy in the lower atmosphere. ► CERTAIN
- ► THE NATURAL GREENHOUSE EFFECT from clouds, water vapor, CO_2, and CH_4 is responsible for some 33°C of natural surface temperature warming. ► CERTAIN
- ► HUMANS HAVE ALTERED the natural greenhouse effect by adding 25% more CO_2, 100% more CH_4, and a host of other greenhouse gases such as N_2O and CFC since the Industrial Revolution. ► CERTAIN
- ► ADDED GREENHOUSE GASES from human activities should have added some 2 to 3 W of infrared radiative energy over every square meter of Earth. This is well-established based on our considerable knowledge of the structure of the atmosphere and on extensive validation from satellites and other measurements—even though the extra 2 to 3 W cannot be directly measured yet. ► VIRTUALLY CERTAIN
- ► EARTH HAS IN FITS AND STARTS, warmed up by ~0.5°C over the past century; the 1980s is the warmest decade on record and 1990, 1991, and 1988 (in order) the warmest years on record. (The warmth of individual years varies with instrument method used—eg, these records are from the surface network of thermometers, not radiosound or satellite instruments.) ► VERY LIKELY
- ► ALTHOUGH NO HIGHLY SIGNIFICANT (ie, at the often-cited 99% statistical confidence limit) cause-and-effect statements between the observed warming and the buildup of human-induced greenhouse gases can be credibly asserted for at least another decade or 2, the likelihood that the 0.5°C 20th century warming trend is wholly a natural phenomenon is small (ie, I would estimate perhaps a 10 to 20% chance). ► LIKELY
- ► MOST CLIMATIC MODELS PROJECT A WARMING of several degrees or so in the next 50 years given standard ("business as usual") greenhouse-gas emission scenarios, and they portend a potential long-term (ie, AD 2100 to 2200) warming commitment as high as 5 to 10°C (eg, IPCC[8]). ► GOOD CHANCE, AT LEAST AN EVEN BET

CFC = chlorofluorocarbons
CH_4 = methane
CO_2 = carbon dioxide
H_2O = water
N_2O = nitrous oxide
SO_2 = sulfur dioxide

STEPHEN H SCHNEIDER, senior scientist, National Center for Atmospheric Research, Boulder, CO, 80307-3000; and professor, Department of Biological Sciences and the Institute for International Studies, Stanford University, Stanford, CA, 94305.

- Natural, *sustained, globally averaged* rates of surface air-temperature change (eg, from the breakup of the last ice age 15 000 years ago to the full establishment of our current interglacial age some 5000 to 8000 years ago) are typically ~1°C/1000 years. On the other hand, even the minimum projected human-induced rates of climate change are on the order of 1°C/100 years up to a potentially catastrophic rate of 5°C/100 years—the latter being some 100 times faster than typical sustained globally-averaged rates of climate change to which human civilization evolved, and the current distribution of species and ecosystems emerged. ▶ VERY LIKELY
- MOST FOREST SPECIES "MIGRATE" at rates of at most 1 km/y, and would not be able to "keep up" with temperature changes at a rate of several degrees centigrade per century without human intervention to transplant them (ie, ecological engineering).[4] ▶ VERY LIKELY
- DIFFERENT SPECIES (eg, specific kinds of trees, insects, birds, or mammals) would all respond differently to projected climatic changes. For example, birds can migrate rapidly but the vegetation some birds need for survival habitat would respond only very slowly (over centuries). This implies a possible tearing apart of the structures of communities of plants, insects, and animals (eg, T L Root[20]) at rates that exceed clear historic or geologic metaphors (eg, R W Graham and E C Grimm[6]). ▶ LIKELY
- CURRENT ENGINEERING AND ECONOMIC PRACTICES in terms of building standards, automobiles, power production, or manufacturing are very retarded relative to the energy efficiency of best available technologies or techniques. Many studies[eg,13,15] show that from 10 to 40% reductions in current CO_2 emissions in the United States could result in long-term costs at or below current rates of expenditure for the equivalent energy services if current inefficient practices and infrastructures were replaced by state-of-the-art, proven efficient practices and equipment. ▶ VERY LIKELY

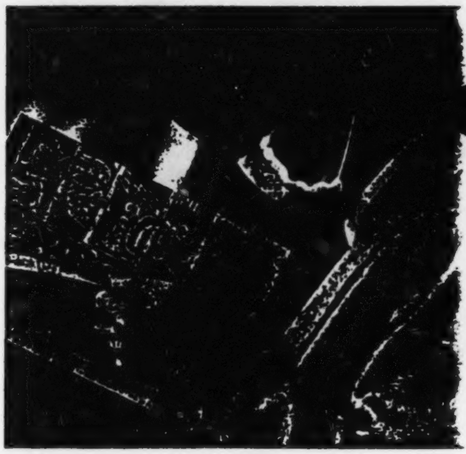


Figure 2.
Although air-pollution levels have recently improved, surgical masks are worn by those troubled by the still-high pollution levels on Honshu Island, in Tokyo, Japan.
DAVID ALLAN HARVEY

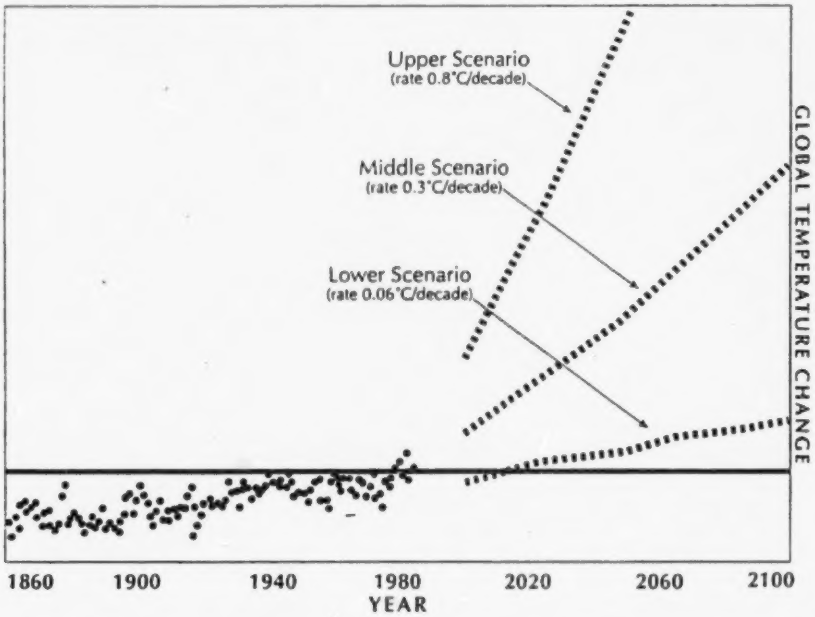


Figure 3.
Three scenarios for global temperature change to 2100 derived from combining uncertainties in future trace greenhouse-gas projections with those of modeling the biotic and climatic response to those projections. Sustained global temperature changes beyond 2°C (3.6° F) would be unprecedented during the era of human civilization. The middle to upper range represents climatic changes at a 10 to 100 times faster pace than long-term natural average rates of change.[9]

The uncertainties in temperature projections over the next century range over a factor of 10 (Figure 3). Including together, uncertainty from human behavioral activities that create greenhouse-gas emissions, biological factors that influence the carbon cycle, and physical factors such as the "feedback effects" of clouds or ice, leads to the differences seen on Figure 3.[9]

Figure 4.
Terraced rice fields on the island of Bali are common. Taking advantage of the run-off from nearby mountains, these fields produce as many as 3 crops a year with centuries-old irrigation systems.
CHARLES O'REAR

Figure 5. (opposite page)
Chisso Company, Minamata, Japan, 1971.
JAMES L STANFIELD

BEST COPY AVAILABLE

What Is Known with Some Reliability?

A major criticism of global warming has been the imperfect match between the erratic warming of the Earth and the relatively smooth increase in greenhouse gases over the past 100 years. It has been alleged that the temperature trends in the 20th century cannot be attributed to greenhouse-gas buildup, because most of the warming in the 20th century took place between 1915 and the 1940s, followed by a cooling at the very time the global greenhouse gases began to build up rapidly. Then, from the mid-1970s to 1992 there has been a dramatic warming, with the past 12 years of surface temperature containing over a half dozen of the warmest years on record.

Unfortunately, we cannot rule out some possible role for other potential climatic influences or "forcings" as they are called. Among these forcings are: sunspot activity or atmospheric particles from volcanic eruptions, industry, automobiles, and agriculture (Figures 1,2,4,5). It has long been known that most of these particles, for example, tend to cool the planet, counteracting any greenhouse effect, at least regionally.

Very recently, R J Charlson and colleagues[1] picked up on this old debate[eg,2,21,24] of the cooling potential of human emissions of SO_2 (largely from burning sulfur-contaminated oil or coal) and added some quantitative insights. They concluded that sulfuric acid aerosol particles (a form of smog) could both directly and indirectly (by brightening clouds) reflect enough sunlight away so as to nearly compensate for the extra human-caused greenhouse-effect surface-layer heating from CO_2, CH_4, and CFC over most of the Northern Hemisphere landmasses since the 1960s. Since this reflection of sunlight is a daytime phenomenon but the addition of greenhouse gases is a day and night effect, scientists (see, for example R A Kerr[10]) recently have begun to project that the SO_2 effect combined with the anticipated global warming from greenhouse-gas emissions would, at least over land in the Northern Hemisphere, result in a nighttime warming trend. Recently, T R Karl and colleagues[11] noted that over the United States, the former Soviet Union, and China (precisely those places most affected by SO_2 emissions), recent (ie, within the past 30 years) warming trends were indeed largely at night. While 30 years is too little time to allow any confident conclusions, these latest results add (not subtract as some critics have contended) to the confidence that greenhouse-gas buildup equivalent to a doubling of CO_2 would eventually warm the Earth by some 1.5 to 4.5°C. This is all noted in the recent update of the Intergovernmental Panel on Climate Change report.[8]

Finally, for 2 reasons we should take little comfort from the possibility that sulfuric acid particles will "save us" from global warming. First, such chemicals are principal ingredients of acid rain (Figures 19 & 20) and health-threatening smog. Second, aerosols are, as many have noted for decades[eg,23,24] a regional phenomenon, whereas "greenhouse" heat-trapping effects are spread fairly uniformly over the globe. Thus, even if on a hemispheric average sulfur aerosols were to exactly reject as much extra solar heat to space as greenhouse gases trapped heat in the infrared wavelengths near the surface, this situation would not be a cancellation of climatic effects, since the cooling would be in very patterned half-continent-sized intense patches, whereas the heating would be relatively more evenly distributed around the hemisphere. The likely result would be a distortion of normal heating patterns, such as the land–ocean thermal contrast. Such distortions would likely lead to regional climatic anomalies (ie, unanticipated local or regional climatic events) even if the net hemispheric temperature changes were small as a result of the hemispheric-scale heating–cooling compensations. In short, we cannot "cure" global warming with SO_2 emissions and escape risk free.

An updated interim report of the Intergovernmental Panel on Climate Change acknowledged these uncertainties, while concluding once again that the 1.5 to 4.5°C warming range is quite likely to cover what the actual long-term temperature response to CO_2 doubling will be over the next 50 years or so.

But most scientists still agree that without 10 to 20 more years of thermometer, satellite, solar, atmospheric pollution, and volcanic observations it is difficult to pin anything down to 99% certainty.

Fortunately, we are now measuring energy output of the sun, eruptions of volcanoes, and pollution-generating activities, and can thus account better for their individual effects. Finally, in short, we are watching some of the other forcings. Thus, as greenhouse gases continue to build up in the future, if greenhouse warming does not take place at roughly the predicted rate during the 1990s and into the next century, then it will be possible to argue on the basis of some direct evidence that the effect predicted by current models is off base. Personally, I will be surprised if our current global "best guesses" prove to be off by >50%.

Indeed, speculative theory is not the principal reason that advocates of concern over the prospect of global warming—and I am unabashedly one of them—take their time and stand before groups such as Congressional committees and take their time with our concern. Rather, our concern is based on the validation exercises for models that we have built of the present and past climate, since these models can also be used to foreshadow the future. In fact, many aspects of these models have already been validated to a considerable degree, although not to the full satisfaction of any responsible scientist.

For example, we know from observations of nature that the last ice age, which was ~5°C colder on a global average than the present era, had CO_2 levels ~25% less than over thousands of years before the Industrial Revolution. CH_4, another very potent greenhouse gas, also was lower by about half relative to preindustrial levels.

Ice in Antarctica contains gas bubbles that are records of the atmospheric composition going back over 160 000 years. Cores drilled into the ice sheets show us that the previous interglacial warm age, some 120 000 to 130 000 years ago, had temperatures and CO_2 and CH_4 levels comparable to those in the present interglacial period.

The well-correlated change in these greenhouse gases and in planetary temperature over geological epochs is an empirical way to estimate the sensitivity of climate to greenhouse-gas concentration changes. Such studies find geological-scale temperature changes from greenhouse-gas variations roughly of the magnitude that one would expect based on projections from today's generation of computer models.[7] However, we still cannot assert that this greenhouse-gas–geological-temperature coincidence is proof that our models are quantitatively correct, since other factors were operating during the ice age–interglacial cycles. The best we can say is that the evidence is strong but circumstantial.

One related point to the ice age–interglacial cycles may be useful here. It typically takes tens of thousands of years to build up ice age glaciers,

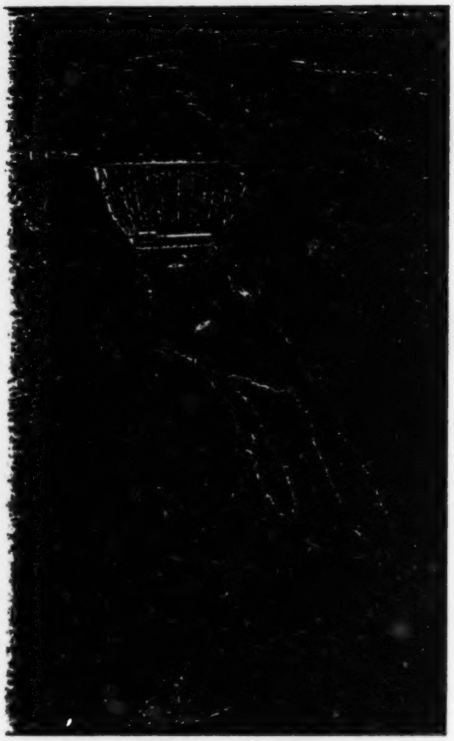


Figure 6.
Drought affects this Colorado River site at Lake Powell and Glen Canyon Dam, near Page, Arizona.
KERBY SMITH

Table 1. The Sensitivity and Adaptability of Human Activities and Nature

HUMAN ACTIVITY AND NATURE	LOW SENSITIVITY	SENSITIVE; ADAPTATION AT SOME COST	SENSITIVE ADAPTATION PROBLEMATIC
INDUSTRY AND ENERGY	▬		
HEALTH	▬		
FARMING		▬	
MANAGED FORESTS AND GRASSLANDS		▬	
WATER RESOURCES		▬	
TOURISM AND RECREATION		▬	
SETTLEMENT AND COASTAL STRUCTURES		▬	
HUMAN MIGRATION		▬	
POLITICAL TRANQUILITY		▬	
NATURAL LANDSCAPES			▬
MARINE ECOSYSTEMS			▬

NOTE: Sensitivity can be defined as the degree of change in the subject for each "unit" of change in climate. The impact (sensitivity times climate change) will thus be positive or negative depending on the direction of climatic change. Many things can change sensitivity, including intentional adaptations and natural and social surprises, and so classifications might shift over time. For the gradual changes assumed in the National Academy of Sciences study, the panel believes these classifications are justified for the United States and similar nations.

SOURCE: National Academy Sciences.[13]

BEST COPY AVAILABLE

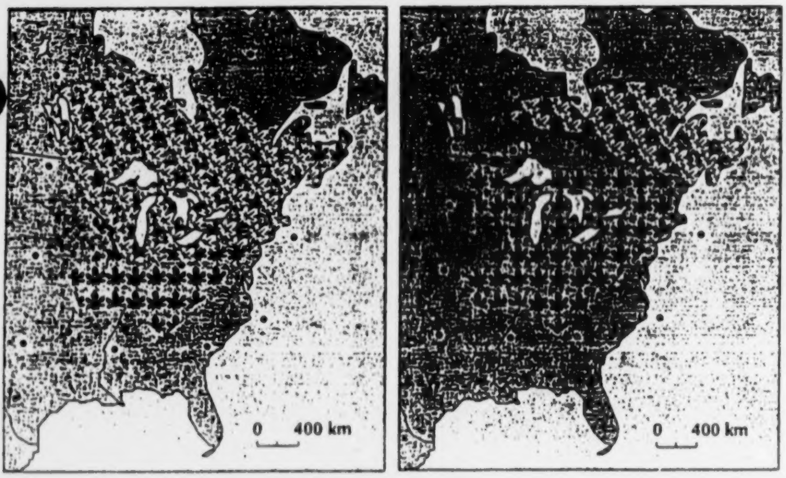


Figure 7.
Present geographical range of sugar maple (red leaves) and potentially suitable range under doubled CO_2 (yellow leaves). A. predictions use climate scenarios derived from the Goddard Institute for Space Studies general circulation model; B. predictions use climate scenarios derived from the Geophysical Fluid Dynamics Laboratory model. Gridpoints are sites of climatic data output for each model. [5]

but only ~10 000 years to deglaciate; and each warm interglacial epoch also lasts typically 10 000 years. Since our current interglacial is now ~10 000 years old, some have suggested that global warming is a good thing because it will hold back the next ice age. What this view ignores is that the time frame for natural interglacial to glacial transitions is tens of thousands of years, whereas the potential for global warming is 2 to 10°C warming in only a century or 2—a radical rate of climatic change relative to most sustained, natural global climate changes in geological history.

What Is Highly Speculative?

Any prediction of what climatologists call the detailed time-evolving, regional distribution of climatic anomalies is highly speculative. It is still tough to be confident in projecting where and when it will be wetter and drier—how many floods might occur in the spring in California, or forest fires in Wyoming or Siberia in August—although some plausible scenarios can be given (pp 180&181; Figures 18&21) . How much sea level will change is also speculative,[eg.22] with most estimates ranging from 0 to 1-m rise by 2100.

ECOLOGICAL IMPACTS: THE POTENTIALLY MOST SERIOUS CONSEQUENCE

Projecting the time required for regional climatic changes to evolve is still speculative, and so too is any confident assessment of the agricultural, hydrological, ecological, or health consequences of global warming. However, we can construct a variety of plausible specific scenarios of climatic changes over space and time and then ask: "So what?"[eg.16,25] Indeed, such exercises have led to conflicting assessments of the agricultural consequences (Table 1),[eg.13] but greater concern for the hydrological consequences[eg.26] and very serious concern for the ecological implication of most global warming scenarios (Figure 6).[17]

Figure 7 shows distribution of sugar maple trees (Figure 8) under 2 different estimates of climatic changes. The authors of this study noted that their estimates of changes in the ranges of this species did not account for the time it might take for the trees to migrate or the obstacles they might encounter in migration (eg, farms, cities, freeways, acid precipitation, air

Figure 8.
Sugar maple trees, near Algonquin Provincial Park, Ontario, Canada.
DAVID S BOYER

BEST COPY AVAILABLE

Figure 9.
The distribution and abundance of the winter range of the eastern phoebe. The northern boundary of this bird in winter lies very close to the –4°C isotherm of January minimum temperature (heavy solid line).

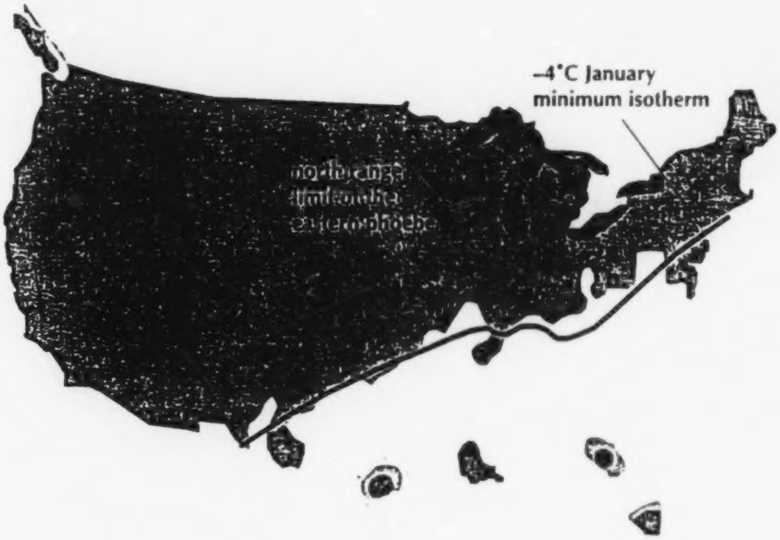


Figure 10.
An eastern phoebe (Sayornis phoebe) perches on a branch in Everglades National Park, Florida.
BATES LITTLEHALES

pollutants). Indeed, as University of Minnesota ecologist Margaret Davis[4] noted:

> *The fossil record shows that most forest trees were able to disperse rapidly enough to keep up with most of the climatic changes that took place in recent millennia. These changes were much more gradual than the climatic changes projected for the future. Even so, there were occasional periods of disequilibrium between plant distributions or abundances, soils, and climate that lasted a century or more. The most rapid dispersal rates known from the fossil record, however, are an order of magnitude too slow to keep up with the temperature rise expected in the coming century.*

University of Michigan ecologist Terry Root, additionally, shows the difference for a species of bird (the eastern phoebe, Figure 10) whose winter northern range limit has a close association with mean minimum January temperature; but this winged animal could migrate very rapidly in response to climatic changes (Figure 9). On the other hand, Root, who studied the associations among >100 birds and environmental factors, such as temperature or vegetation, discovered that many species of birds associate with both temperature and vegetation (Figure 11).[18,19] She further noted[20] that birds that are physiologically constrained by low temperatures alone could migrate north when it warms, but those that are also restricted by habitat (eg, vegetation patterns) may have to wait centuries for their required vegetation to migrate before they could shift. In the interim, then, what is likely to occur is a "tearing apart" of the structure of ecological communities, alteration of predator–prey interactions and the potential for "ecological chaos" during the few centuries it will take for climate to warm from a few to 10°C and for the various individual species to respond. Such disruption to "natural balances" would likely enhance extinction, especially for the many species that have limited habitat ranges and are strongly associated with climatic variables.[eg,12]

It is already a formidable scientific challenge to try to explain the range limits and abundance of most species today, even though they have had thousands of years of stable climate to adapt to. Therefore, to predict the highly transient response of biological communities faced with sustained global climatic changes at 10 to 100 times faster rates than natural average rates of climatic change over the past 15 000 years is speculative at best! However, we do have some knowledge, as previously indicated, of what factors can affect individual species and roughly how rapidly they can respond to various disturbances. Therefore, qualitative statements such as "disruptions of ecosystems," "tearing apart of communities of species," or even "ecological chaos" are plausible "forecasts" should global warming materialize at typically projected rates of 1 to 5°C over the next 100 years.

Other aspects of the global warming issue that are highly speculative are the overall social or economic consequences of typical warming scenarios or the costs of actions to mitigate CO_2, CH_4, N_2O, or CFC emissions or whether to use technological schemes to offset warming (ie, so-called geoengineering).[13]

Although climatic models are far from fully verified for future simulations, the seasonal and paleoclimatic (dealing with remote ages) validation exercises modelers perform are strong evidence that state-of-the-art climatic models already have considerable forecasting skill. And, uncertainties are as likely to render current "best guesses" underestimates as overestimates.

An awareness of just what simulation models are and what they can and cannot do is probably the best we can ask of the public, journalists, and political leaders. Then the tough policy problem is how to apply society's values in choosing to deal with the future given the wide range of possible outcomes that climatic models project.

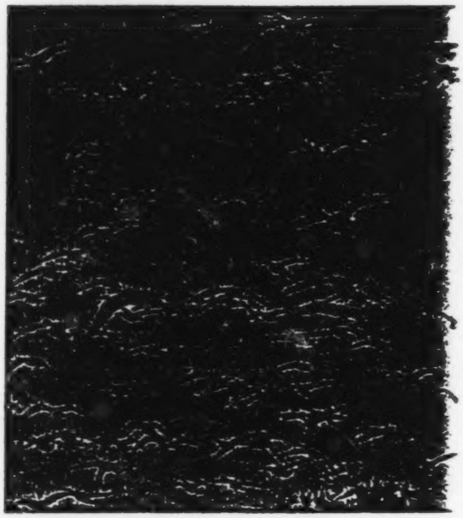


Figure 11.
Gaddy's Wild Goose Refuge, Ansonville, North Carolina.
FREDERICK KENT TRUSLOW

Is It Too Expensive to Act Now?

The final, and perhaps most important, criticism against those proposing action to slow global warming is that the immediate policy steps to decrease CO_2 emissions are too expensive. For example, some newspaper ads by greenhouse critics suggest that if CO_2 emissions are cut, the United States will be bankrupt and the Third World impoverished.

There is substantial Third World opposition to the prospect that developing countries may not be able to have their own industrial revolutions as the developed countries did in the Victorian period when those then-developing Western countries used unregulated amounts of cheap and dirty coal to foster their industrial growth.

Some now-developing countries, notably India and China, have abundant coal supplies (Figure 1). They would like to repeat Western history and use them as low-cost routes to industrialization. Of course, these countries in the 1990s have between them 2 billion people whereas the entire world did not have 2 billion people in Victorian times. So the magnitude of the global impact of now-developing countries' use of coal—should they use coal to produce even a quarter of the West's current industrial standard of living—would be greater than that of developing Western nations in the past. Needless to say, such arguments are not greeted sympathetically in China or India.

The media debate over global warming frequently polarizes scientists into the "end of the world" or "nothing bad will happen" factions, even though the scientific community at large views these as the least probable outcomes. This false dichotomy is followed by policy grid lock. We need to self-consciously distinguish what is well-known and accepted, what is a good bet, what is highly speculative—and what is scientific (ie, assessing probabilities of various outcomes) from what is a value judgement (what to do given the probabilities and consequences scientists provide).

CAN CO_2 EMISSIONS BE CUT 20%?

It is sensible, I believe, to argue that now-developing countries need not repeat the experience of Victorian industrialization with smog-choked cities, acid rain, and inefficient power production, given that modern technology has many better solutions. For example, electrical power-genera-

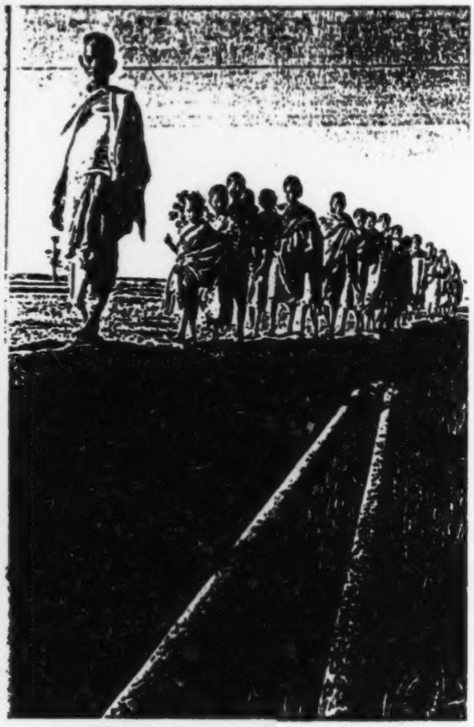


Figure 12.
Phusriguda village, Orissa, India. Rice field irrigation.
JAMES P BLAIR

tion efficiency today is near 50%, whereas it was half that at the turn of the century. Unfortunately, developing countries typically respond that high-technology, efficient power production is initially more expensive than the traditional options that are cheaper and more available to them. This dilemma sets up the need for a bargain by which developed countries with technology and capital help to provide those resources to developing countries, which in turn develop their economies with the lowest polluting, most efficient technologies, even if they cost more initially.

There have been international efforts afoot to have each nation on Earth commit itself to try to decrease its CO_2 emissions by, say, 20% by the year 2000. This target reduction had been strongly opposed by the United States, as well as some other countries. The Japanese were initially unhappy since they are already about twice as energy efficient as the United States. They claimed it would cost them much more to cut their CO_2 emissions by 20% than the United States, whose relative inefficiency gives it more opportunity to cut cheaply. Nonetheless, the Japanese have recently endorsed specific CO_2-emission limits in the context of the United Nations Conference on Environment and Development.

Developing countries, being even less energy efficient than the United States could, with modest investment, produce vastly less growth in CO_2 (the principal greenhouse gas) pollution if efficient, modern technologies were used rather than the older, cheaper, and readily available technologies, such as low-efficiency coal burning in China or India. The modern technologies that could be tapped by industrializing nationals range from fluid-bed coal burning, nuclear, hydro, geothermal, natural gas, wind, biomass, solar, and possibly, in the very long term, fusion power. This circumstance sets up the possibility for creative international management that might not only eliminate Third World opposition to global emissions reductions but also get them to compete with each other to be the venue for future emissions limitations funded by developed countries. A developed nation could buy itself out of its 20% cut requirement by funding even larger CO_2 reductions in energy inefficient developing nations.

Critics of emissions reductions cite the supposed annual cost of 20% CO_2 reduction at tens to hundreds of billions of dollars. But they often neglect the benefits of emissions reductions: reduced magnitude of global warming, reduced acid rain, reduced urban air pollution, reduced balance-of-payments deficits, and lower long-term operating costs of manufactured products, enhancing competitiveness. Such critics simply cite the potential initial capital costs of CO_2 controls or carbon taxes, write newspaper stories about how many billions each year or trillions over a century it will cost, and scare people away from anti-pollution action.

Like most other decisions at personal, corporate, state, national, or international levels we face value choices that trade present and future risks against mitigation-policy costs. The environmental sciences are not entitled to a higher standard of scientific certainty than any other area of decision making with a higher degree of technical uncertainty.

Some studies have suggested that carbon taxes to promote switching to less polluting energy systems could cost the United States alone "$800 billion, under optimistic scenarios of available fuel substitutes and increasing energy efficiency, to $3.6 trillion under pessimistic scenarios... to [the year] 2100." This quote from the February 1990 "Economic Report of the President" to Congress was based on the initial results of the first wave of economic model simulations.

Because of the controversy associated with such models, the National Academy of Sciences ran a debate among several economic forecasters and their critics. The result was revealing. First, over 110 years (ie, 1990 to 2100) even a trillion dollars in accumulated CO_2 reduction costs, which

Figure 13.

Leshan, Sichuan province, People's Republic of China. Chinese women stand on top of a mountain of coal as they shovel it into an open-sided train car.

JODI COBB

sounds expensive, is <$10 billion each year—only a few percent of the annual U S defense budget. Moreover, Robert Williams, an energy technology specialist from Princeton University, pointed out that the so-called optimistic scenario of $800 billion in costs to cut U S CO_2 emissions was based on pessimistic assumptions about the rapidly decreasing costs of renewable energy systems like solar, wind, or biomass power.

Furthermore, with the exception of a heroic effort by Yale University economist William Nordhaus, the economists' simulations usually do not even attempt to estimate what direct environmental benefits the United States (or the world) gets for its supposed trillion-dollar investment in CO_2-emission controls. It is unconscionable that some critics of global warming action could cite these already very dubious economic models' cost estimates without so much as a word on the potential benefits of slowing CO_2 emissions. Nordhaus, on the other hand, by balancing costs and benefits in his model runs, argued that cutting annual CO_2 emissions by as little as 10% or as much as 47% would actually produce benefits greater than the costs. However, his model, too, is admittedly crude, laden with unprovable assumptions, and simply cannot by itself provide quantitatively reliable information upon which to base policy choices.

Finally, cross-examination of several economists by National Academy committee members disclosed that their economic models had not even been tested to see how well they performed in predicting the economic

Figure 14.
The carbon tax that would be necessary to raise fossil fuel prices enough in Nordhaus[7] model to achieve the desired policy objective indicated by the color chart to the right.

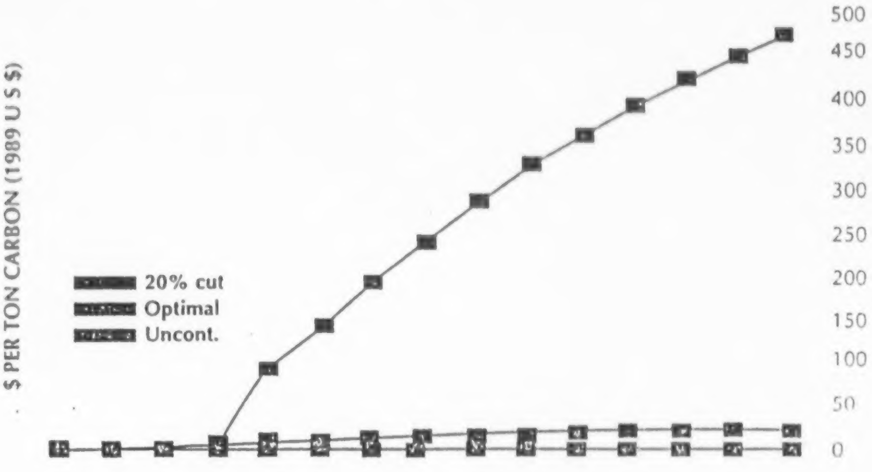
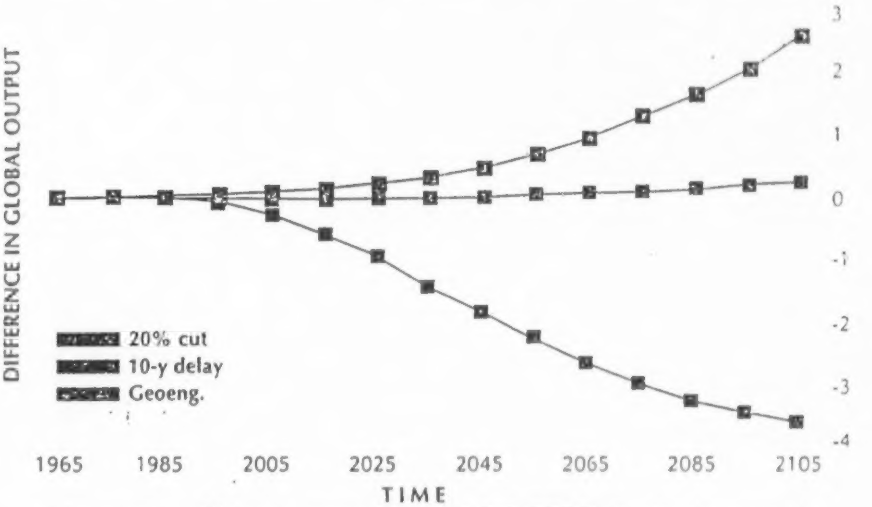


Figure 15.
The impact on Nordhaus[7] economic model of the different policies shown on the figure. Note for perspective that current global output is around $20 trillion per year and in Nordhaus[7] future world gross global output grows to over $100 trillion per year by 2105, with or without CO_2 emissions taxes (see Figure 17).[14]



consequences of historic events like the 1973 OPEC oil price increase. As a participant at that debate, I was concerned that such validation tests were yet to be performed, and dismayed that some global warming critics were actually citing as an alleged rational basis for national policymaking these highly preliminary economic model results for costs of emission controls or taxes without weighing in benefits of such taxes.

Let us pursue the economic modeling issue a bit further. When only the supposed costs to the economy (typically measured as loss of gross national product [GNP] from a hypothetical carbon tax) are shown, seemingly staggering figures emerge (Figure 14). For 1 economic model,[14] the costs run into the trillions by 2105 (Figure 15). The benefit of this "20% cut" Nordhaus calculates (Figure 16) is a 30% reduction in global warming by 2105, only "worth" a percent or less of GNP by Nordhaus' assumptions—since he assumes the primary negative economic consequence of warming to be an agricultural and water supply loss of ≤1% of global GNP (in the United States ~$40 billion per year). He puts no value on the potential for catastrophic effects on ecosystems or the security implications of long-term, very large climatic changes (perhaps ~10°C in the 22nd century as W R Cline noted in his recent economic analysis[3]). Effects such as the tearing apart of communities of species or the impacts on the political stability of South Asia were tropical cyclone intensities to increase are

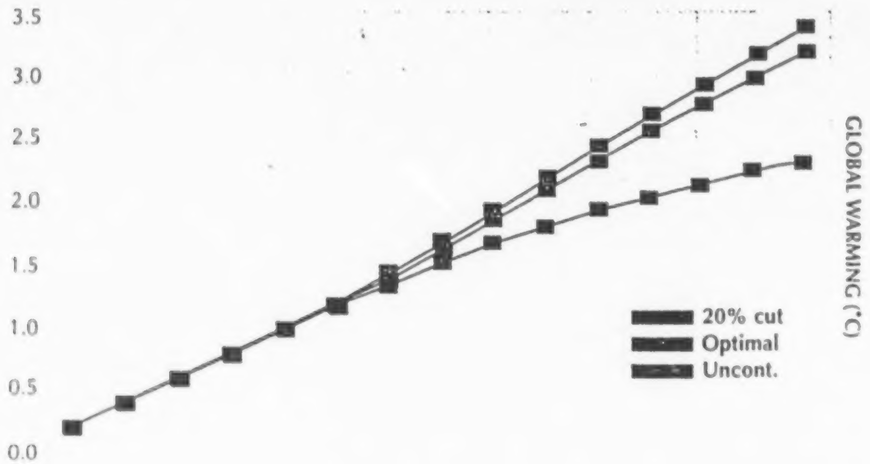


Figure 16.
The projected reduction in global surface temperature increase for the CO_2 emissions scenarios generated by Nordhaus[2] *model based on policy alternatives given on Figure 14.* [14]

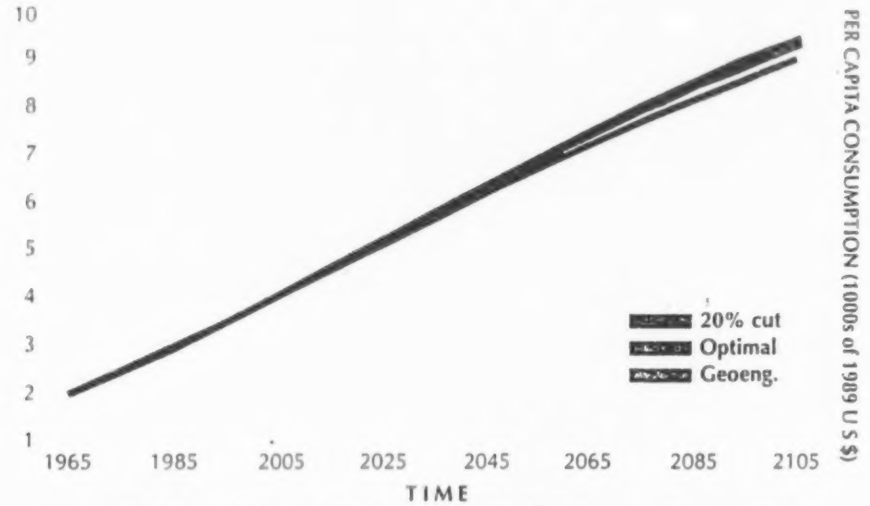


Figure 17.
Projection of real consumption per capita (in thousands of 1989 U S $) for the 3 policy cases on Figure 15. Note that even the so-called draconian 20% CO_2 emissions cut scenario still leads to some 450% growth in this measure of economic well-being, calling into question statements that suggest greenhouse effect controls via carbon taxes would be economically catastrophic. [14] *This figure from the original complete Nordhaus manuscript was omitted from the abridged version published in Science.*

not explicitly considered. But to his credit, Nordhaus makes explicit in Figure 17 (from his original unabridged manuscript[14]) his underlying economic growth assumptions that drive his conclusions. In fact, as Figure 17 shows, there is a >450% growth in per capita consumption from 1965 to 2105 in all his scenarios, and even the "draconian" 20% cut carbon tax scenario still allows 450% growth over this period!

I believe it is shortsighted to risk unabated, unprecedentedly rapid rates of climate change with potentially serious risks to agricultural, hydrological, and (especially) ecological systems of the Earth merely because it will reduce our per capita growth in consumption from some 460% to "only" 470%! It would only take a decade or so more of such growth to achieve "uncontrolled" economic well-being levels in the "20% cut" scenario that so many label draconian. To show Figure 14 with trillions of dollars of potential costs from carbon taxes without also looking at Figure 17 is to have no balanced perspective on the economics and ethics of measures that could mitigate CO_2 emissions. (And even this 20% cut scenario implies major increases in CO_2 emissions associated with traditional growth patterns.)

In any event, while it is possible to use analytic methods and simulation models to investigate costs and benefits of different specific climate-change or emission scenarios, these tools are even less well-validated for

BEST COPY AVAILABLE

Table 2. Cost Effectiveness Ordering of Geoengineering Mitigation Options

Mitigation Option	Net Implementation Cost	Potential Emission Mitigation (t CO_2 equivalent per year)
Low Stratospheric soot	Low	8 - 25 billion
Low stratospheric dust, aircraft delivery	Low	8 - 80 billion
Stratospheric dust (guns or balloon lift)	Low	4 trillion or amount desired
Cloud stimulated by provision of cloud condensation nuclei	Low	4 trillion or amount desired
Stimulation of ocean biomass with iron	Low to Moderate	7 billion or amount desired
Stratospheric bubbles (multiple balloons)	Low to Moderate	4 trillion or amount desired
Space mirrors	Low to Moderate	4 trillion or amount desired
Atmospheric CFC removal	Unknown	Unknown

Note: The feasibility and possible side-effects of these geoengineering options are poorly understood. Their possible effects on the climate system and its chemistry need considerably more study and research. They should not be implemented without careful assessment of their direct and indirect consequences.

Cost-effectiveness estimates are categorized as either savings (for less than 0), low(0 to \$9/t CO_2 equivalent), moderate (\$10 to \$99/t CO_2 equivalent), or high (>\$100/t CO_2 equivalent). Potential emission savings (which in some cases include not only the annual emissions, but also changes in atmospheric stock) for the geoengineering options are also shown. These options do not reduce the flow of emissions into the atmosphere but rather alter the amount of warming resulting from those emissions. Mitigation options are placed in order of cost-effectiveness.

The CO_2-equivalent reductions are determined by calculating the equivalent reduction in radiactive forcing.

Source: National Academy of Sciences, Chapter 11.[13]

long-term studies than climatic models and also do not include many significant factors the authors usually acknowledge. In my opinion, all physical, biological, or economic analytical methods are primarily useful to help a decision maker to obtain a more complete knowledge of the potential benefits or risks of various alternative actions, so as to aid him or her in formulating a heuristic judgment that incorporates what is quantifiable with aspects that are not (eg, the "value" of a species facing extinction). It is a gross misunderstanding of analytical methods, be they climatic, ecological, or economic, to believe they provide the sole bases for arriving at "the answer" on either the effects, consequences, or mitigation policy aspects of global change.

Figure 18.
San Cristobal, Dominican Republic. Ruins and remains from a hurricane.
JAMES P BLAIR

Climatic "Insurance"

The global-warming debate then is both science and politics. But it is essential for the public to understand that there are vastly greater disagreements over what to do about the prospect of global warming (ie, a political value issue) than over the probability (ie, a scientific debate) that unprecedented climate change is being built into the 21st century climate. Estimates of climatic effects range from mildly beneficial (ie, longer growing seasons) to highly catastrophic (ie, more super hurricanes or mass extinctions). These uncertain impacts reflect the wide range of climate futures forecast by most assessment groups, such as those in Figure 3. Although accelerated research will undoubtedly bring more reliable answers sooner, thereby helping to place decision making on a firmer factual basis; I do not believe it likely that any feasible level of research effort

BEST COPY AVAILABLE

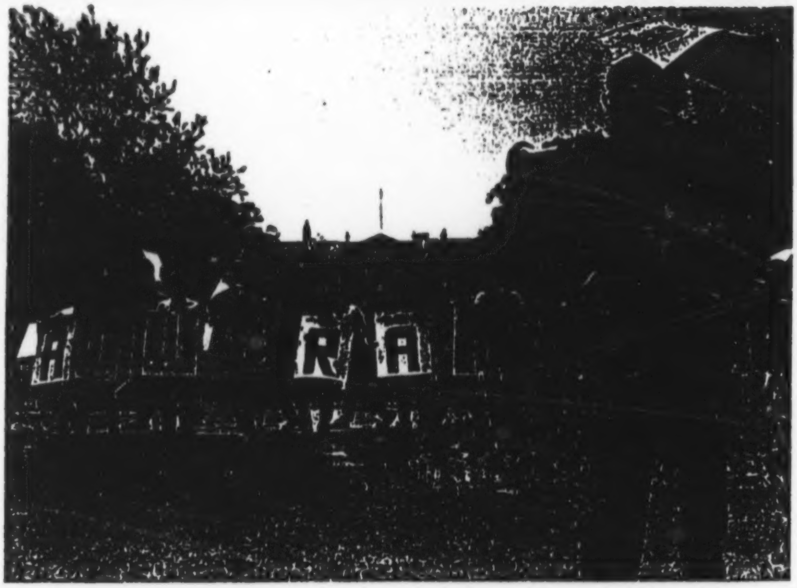


Figure 19.
Lafayette Square, Washington, DC. An acid rain protest sponsored by the U S Public Interest Research Group, Sierra Club, Greenpeace, and the National Clean Air Coalition. The man with the megaphone is Danie[illegible]ker of "Environmental A[illegible]
SARAH LEEN

will pin down the *detailed* environmental or societal consequences of our continuing greenhouse-gas emissions in less than a few decades—the time it will take the climate system itself to answer the question.

Slowing down the buildup rate of the greenhouse gases that threaten unprecedented global warming does not require economically catastrophic measures, nor must it bankrupt industrial nations or doom the poor countries to increasing poverty. Rather, prudent investments in energy-efficient equipment, houses, and power plants combined with sensible reforestation and population-control programs, can both reduce the buildup rate of greenhouse gases and pay their own way. It is ludicrous simply to charge that greenhouse-gas emission cuts are too costly, without weighing the economic, environmental, and strategic benefits of such investments. No individual or business ever got a return without first making an investment. That applies as well to societies and governments—the level at which global-change problems occur and must be addressed.

Every insurance policy has a premium, of course. But these environmental investments not only buy "insurance" against the possibility of unprecedented, possibly dire, climatic change but also can pay large dividends in the form of lowered energy costs, lower balance-of-trade payment deficits, less local air pollution, and lowered acid rain. Therefore, such strategies make sense, even if global warming turns out to be as insignificant as the critics assert. In any case, since mild climatic effects are as probable as catastrophic ones, and since it will take many decades to resolve major uncertainties, we can take the most cost-effective steps now, and then press more or less to mitigate further as new national and international scientific assessments report the latest findings of the scientific community every few years over the next several decades.

But if the warming turns out to be as bad as or worse than most current "best guess" projections, such climate insurance will have been very wise indeed.[8] An insurance policy that pays big dividends on the premium even if the catastrophe never materializes, it seems to me, is the most rational response to the coin-flipping probabilities of unprecedented climate change and attendant ecological disarray that most knowledgeable scientists agree we are facing as we enter the next millennium. None of the noisy polemics of the past few years has changed that basic consensus.

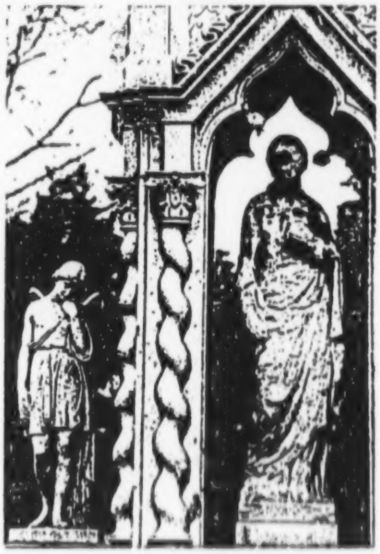


Figure 20.
Statues in a Louisville, Kentucky cemetery illustrate the effects of acid rain, created by the reaction between atmospheric moisture and fossil-fuel emissions. A black crust forms on the Madonna because it is sheltered, while the angel has no buildup because of the scouring but nevertheless corrosive action of the rain.
TED SPIEGEL

BEST COPY AVAILABLE

Figure 21.

Herders lead bony cattle to water across cracked patches of mud in Rajasthan, India. After the monsoons, this area will be a lake.

STEVE McCURRY

REFERENCES

1. **Charlson, R J, Langner, J; Rodhe, H; et al:** Perturbation of the northern hemisphere radiative balance by backscattering from anthropogenic sulfate aerosols. *Tellus* 43ab:152–163; 1991.

2. **Charlson, R J; & Pilat, M J:** Climate: The influence of aerosols. *Journal of Applied Meterology* 8:1001–1002; 1969.

3. **Cline, W R:** *Global Warming: The Economic Stakes.* Institute for International Economics, Washington, DC; 1992.

4. **Davis, M B:** Climatic change and the survival of forest species. Woodwell, George M, editor: *The Earth in Transition: Patterns and Processes of Biotic Impoverishment*, p 108. Cambridge University Press, Cambridge; 1990.

5. **Davis, M B; & Zabinski, C:** Changes in geographical ranges resulting from greenhouse warming effects on biodiversity in forests. Peters, R & Lovejoy, T, editors: *Global Warming and Biological Diversity.* Yale University Press, New Haven; 1992.

6. **Graham, R W; & Grimm, E C:** Effects of global climate change on the patterns of terrestrial biological communities. *Trends in Ecology and Evolution* 5(9):289–292; 1990.

7. **Haoffert, M J; & Covey, C:** Deriving global climate sensitivity from Paleoclimate reconstructions. *Nature* 360:573–576; 1992.

8. **Intergovernmental Panel on Climate Change:** *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment.* Houghton, J T, Jenkins, G J, & Ephraums, J J, editors. Cambridge University Press, Cambridge; 1992.

9. **Jager, J:** *Developing Policies for Responding to Climatic Change, a Summary of the Discussions and Recommendations of the Workshops Held in Villach 28 September to 2 October 1987.* World Meteorological Organization, Geneva, WCIP-1, WMO/TD-no 225; 1988.

10. **Kerr, R A:** Pollutant haze cools the greenhouse. *Science* 255:682–683; 1992.

11. **Karl, T R; Kukla, G; Razuvayev, V N; et al:** Global warming: Evidence for asymmetric diurnal temperature change. *Geophysical Research Letters*; 18(12):2253–2256; 1991.

12. **McDonald, K A; & Brown, J H:** Using montane mammals to model extinctions due to global change. *Conservation Biology*; 6(3):409–415; 1992.

13. **National Academy of Sciences:** *Policy Implications of Greenhouse Warming.* National Academy Press, Washington, DC; 1991.

14. **Nordhaus, W:** Rolling the "dice": An optimal transition path for controlling greenhouse gases. Paper presented at the Annual Meetings of the American Association for the Advancement of Science, Chicago; 1992. [Shortened version (which omits Figure 17) appears as: An optimal transition path for controlling greenhouse gases. *Science* 258:1315–1319; 1992.]

15. **Office of Technology Assessment:** *Changing by Degrees, Steps to Reduce Greenhouse Gases.* U S Government Printing Office, Washington, DC; 1991.

16. **Pearman, G I, editor:** *Greenhouse: Planning for Climate Change.* CSIRO, Melbourne, Australia; 1988.

17. **Peters, R; & Lovejoy, T, editors:** *Global Warming and Biological Diversity.* Yale University Press, New Haven, CT; 1992.

18. **Root, T L:** Environmental factors associated with avian distributional boundaries. *Journal of Biogeography* 15:489–505; 1988.

19. **Root, T L:** Energy constraints on avian distributions and abundances. *Ecology* 69:330–339; 1988.

20. **Root, T L:** Effects of global climate change on North American birds and their communities. Kingsolver, J, Kareiva, P, & Huey, R, editors: *Biotic Interactions and Global Change*, pp 280–292. Sinauer Associates, Sunderland, MA; 1992.

21. **Schneider, S H:** A comment on "Climate: The influence of aerosols." *Journal of Applied Meterology* 10: 850–841; 1971.

22. **Schneider, S H:** Will sea levels rise or fall? *Nature* 356:11–12; 1992.

23. **Schneider, S H; & Mesirow, L E:** *The Genesis Strategy: Climate and Global Survival.* Plenum Publishing, New York; 1976.

24. **SMIC Report:** *Study of Man's Impact on Climate.* MIT Press, Cambridge, MA; 1971.

25. **Smith, J B; & Tirpak, D, editors:** *The Potential Effects of Global Climate Change on the United States: Draft Report to Congress*, vol 1 & 2. U S Environmental Protection Agency, Office of Policy Planning and Evaluation, Office of Research and Development. U S Government Printing Office, Washington, DC; 1988.

26. **Waggoner, P E, editor:** *Climate Change and US Water Resources.* John Wiley & Sons, New York; 1990.

BEST COPY AVAILABLE